

TEMPORAL CHANGES IN FISH ASSEMBLAGES OF THE FLY RIVER: RIVERINE AND FLOODPLAIN SITES



Report prepared for

Ok Tedi Mining Ltd

By

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Frontispiece: Sampling at Kuambit with the small beach seine

1 Executive Summary

Temporal changes in fish community structure at key riverine and floodplain sampling locations in the Ok Tedi and Fly River were examined using multivariate analysis. The aims were to assess the extent of a.) natural and mine-related changes in fish assemblage structure at each site, and b.) declines/losses of species from parts of the system.

Multivariate analysis is the examination of numerous variables simultaneously. In this instance, it is the simultaneous analysis of the abundance values of each individual species of fish across sites and sampling occasions to derive similarity amongst sites based on fish assemblage composition.

A multivariate approach has the advantage over more traditional univariate methods (i.e. analysis of variance, correlation and linear regression) of assimilating the combined changes in the whole fish community at a site over time. Community-level analysis also provide a multi-species response to possible impacts, which integrates response to changing conditions over time. Changes in community structure may also be extrapolated to indicate overall ecosystem health through changes in processes such as food web interactions, competition, predation etc.

Current analyses were performed to assess the extent of continued changes in fish assemblages at individual sites over time, changes in the occurrence of species at sites over time, and the loss of species from parts of the system, or from the system as a whole. Previous analyses by OTML looked only at riverine sites. However, current analyses were extended to floodplain sites which have not been analysed using these methods since the early 1990s, and there was a potential for declining catches at some floodplain sites as a result of mine-related effects (i.e. forest die-back, tie channel blockage and potential water quality issues related to intrusion of mine derived sediments into floodplain waterbodies). Analyses were also supported with linear regression analyses of changes in species richness, abundance and biomass against time, as these analyses had not been performed for several years, and would assist in identifying temporal changes in catches at each site.

Temporal changes were assessed using all available data, from the commencement of sampling to March 2004, for each key riverine and floodplain monitoring site:

<u>RIVERINE SITES</u>		<u>FLOODPLAIN SITES</u>	
New Atkamba	TED35	Bosset Lagoon	BOS10
Kuambit	FLY10	Bosset Lagoon	BOS11
Bosset	FLY14	Daviumbu	DAV01
Obo	FLY15	Sembe Oxbow	OXB03
Ogwa	FLY20	Lake Pangua	OXB05
Strickland River	STR01	@ ARM345	OXB06
		Strickland R. Oxbow	OXB08

Temporal changes at each site were assessed by selecting five time periods, each period representing a different mine operating stage, with samples allocated to their respective time periods based on when sampled.

TEMPORAL CHANGES AT RIVERINE AND FLOODPLAIN SITES

Time Period	Baseline & gold only	Gold/copper & copper < 80,000 tpd	Copper > 80,000 tpd (1 - 5 yrs)	Copper > 80,000 tpd (6 - 10 yrs)	Dredge in operation
Code	(Au)	(Au & Cu)	(Cu>80k 5yr)	(Cu<80k 10yr)	(Dredge)
Start of period	December-83	August-87	August-89	September-93	March-98
End of period	July-87	July-89	August-93	February-98	March-04

Analyses of riverine sites showed the same consistent pattern of changes in community structure over time at each site as reported previously. Observed changes were greatest at sites closest to the mine (i.e. Kuambit), but with strong effects also detectable in the Fly River at Bosset and Obo. Changes in species assemblages were supported by significant declines in species richness, abundance and biomass.

Chi-square Contingency Table analyses, which statistically tests for differences in the occurrence of each species in each time period, identified species at most sites which showed changing frequencies of occurrence across time periods. The majority of species had declined in occurrence, with some species no longer recorded from some sites. Of particular concern was the decline of a suite of forktailed catfish at Kuambit, Bosset and Obo. Species losses were most evident at sites closest to the mine (Kuambit, Bosset and Obo).

The main exception to the trend of declining assemblages at riverine sites was at New Atkamba (TED35) where there appeared to be increases in assemblage composition/condition with time, with some fish species being recorded more frequently. This may reflect the benefits of the dredge operation at this site. Alternatively, it could reflect the return of some species in response to reduced flows (and sediment loads) during the El Niño droughts.

Results for riverine sites indicated worsening conditions at sites further downstream of the mine (FLY14 and FLY15). Analyses indicated that some species are becoming even more restricted in their distribution, especially a suite of forktailed catfish which are disappearing from riverine sites. If the trend continues, some species may be lost from the entire middle Fly River as well as the Ok Tedi, which would seriously restrict the systems capacity to recover post-mining. A broader biodiversity study is required to establish the continued presence of these species at sites not routinely monitored by OTML.

Analysis of floodplain sites indicated effects not previously observed at ORWB sites. Sites BOS10, DAV01, OXB03, OXB05 and OXB06 all showed trends of progressive declines in catch and changes in assemblage composition, which are not readily explicable by natural events. There are also declines in species richness, abundance and biomass at floodplain sites over time, and even allowing for effects of droughts and algal blooms (as reported previously, OTML 1996), these declines would still be significant.

Based on potential mine-related pressures at these sites (i.e. forest die-back, deposition of mine derived sediments into waterbodies, and tie-channel blockage), it can only be concluded that mine effects are now progressing onto floodplain sites. This has not previously been observed, and has potential implications for the maintenance of a subsistence fishery on the floodplain.

The mechanisms and processes by which the mine may be affecting floodplain fish assemblages are unknown, but may be inferred. Possible mechanisms are:

- changes in food web structure due to forest die-back around forested floodplain sites,
- loss of floodplain connectivity with the main channel due to tie-channel blockage restricting access to migratory species , and,
- chronic toxicity effects from mine-derived sediments deposited at floodplain sites.

Based on the observed changes in fish assemblages at riverine and floodplain sites, the following recommendations were made:

- The potential risks to fish assemblages of floodplain sites from tie-channel blockage, disruption to food webs from forest die-back and chronic toxicity effects from mine-derived sediment should be assessed.
- A biodiversity study should be used to assess the broader occurrence of species that appear to be in decline at riverine and floodplain sites
- Life history traits of those fish species demonstrating declines over recent years should be reviewed to assess any commonality in traits, particularly if there are traits which could make the species more susceptible to mining effects.
- Gradients in water quality parameters (e.g. TSS, pCu and dCu concentrations) should be incorporated in the above analyses to complement the use of time as a variable. Grouping of samples into El Niño/La Niña climatic events also should be examined.
- Multivariate and Chi-square Contingency Table analysis should be periodically repeated (every 3 years) to assess the extent of continued changes in community structure at key monitoring sites.

2 Introduction

Ongoing monitoring of Fly River fish populations has indicated significant declines in fish catches (biomass and numbers of fish) at the majority of riverine sites downstream of the mine (OTML, 1994, 1995, 1996; Swales *et al*, 1998, 1999, 2000), with the extent of declines reducing in severity with increasing distance from the mine. Analyses (OTML, 1995, 1996, Swales 2000) have also detected changes at floodplain sites, principally related to natural events (i.e. droughts, floods and algal blooms), although declines at sites closer to the mine may be mine related (i.e. at OXB06; OTML, 2000). Analysis of metal levels in fish tissues (flesh, liver and kidney) has also indicated elevated levels of copper in fish taken from riverine and floodplain sites downstream of the mine. Although 'cause-and-effect' has been difficult to demonstrate, correlative evidence strongly suggests the declines and changes in tissue metal levels are related to the discharge of tailings and waste rock from the mine.

Apart from work by Smith & Morris (1992) and OTML (1993), previous and subsequent analyses of changes in fish populations have utilised a univariate approach, either looking at changes in basic key community descriptors at each site over time (i.e. changes in total biomass or total number of species), or have looked at changes (increases/decreases) in biomass and abundance of individual species (OTML, 1995). These analyses give a good indication of what each species is doing in isolation. However, univariate analyses do not give a holistic overview of the overall state of the fish assemblages at each site; they do not indicate how fish community structure as a unit has changed. For instance, it is possible for there to have been total loss and replacement of species at a site over time, but by looking at changes in basic community descriptors (i.e. total biomass, total number of species or diversity), community structure could appear unchanged (i.e. same number of species and same diversity). However, multivariate analysis quickly identifies a change in overall community structure, statistically representing the degree of change (percentage similarity) between communities.

Multivariate approaches are widely used and accepted in community ecology and are useful in that they identify changes in community structure which may be difficult to detect using conventional univariate approaches (Gauch, 1982). An added benefit of multivariate community analysis is that it is possible to also identify individual species that have changed, and, the approach may be used to identify 'gradients' in variables (i.e. water quality parameters) that best correlate to the observed changes in community structure at a site (Belbin, 1995).

To complement the routine use of univariate analyses by OTML, multivariate techniques (classification and ordination) were applied to assess between-site (spatial) and within-site (temporal) changes in fish community structure at riverine sites by Storey (1997). Analyses demonstrated strong spatial and temporal change at most riverine sites, with a suite of species either absent or in decline at sites, particularly those closest to the mine. Analyses by Storey (1997) utilised data collected up to late 1996, and these analyses have not been repeated since. Therefore, the current report was prepared to update these earlier analyses, and specifically to assess the current status of species reported by Storey (1997) to be in decline and also to assess the

status of fish assemblages at floodplain sites. In 1997, there were no detectable effects at floodplain sites that could be attributed to mine-effects. However, mine-related changes at some floodplain sites (i.e. tie-channel sedimentation and die-back of adjacent forest), and apparent declines in fish catch (i.e. OXB06; OTML, 2000) have become evident, and need to be investigated.

3 General Methods

All gill net catch data available for riverine and floodplain sites on the OTML Biological Database were used for these analyses. These consisted of “baseline” and “mine-operating” data. Baseline data were collected in 1983/84, prior to the mine commencing operations in April 1984. However, they were not truly baseline as construction started in 1981 and there were effects in the Ok Tedi from this time onwards – i.e. increased TSS due to construction of the Kiunga – Tabubil Hwy and infrastructure on Mt Fubilan.

Since commencement of mining operations there have been five broad mine-operating phases;

- Gold leachate circuit using cyanide from April 1984 to July 1987
- Gold/cyanide circuit running in parallel with a copper flotation circuit from July 1987 to September 1988
- Copper flotation circuit in isolation from September 1988 to August 1989, processing < 80 000 tonnes of ore per day,
- Construction of additional infrastructure completed in August 1989, enabling the mine to treat > 80,000 tonnes of ore per day at peak production.
- Commencement of dredging of the Lower Ok Tedi in March 1998.

These phases were used to group samples into ‘mine operating periods’ that may reflect differing effects on fish assemblages.

3.1 Sampling methodology

Fish populations were sampled using the standard OTML gill-net set, using standardised procedures. During the late 1980s and 1990s sampling was carried out quarterly at most sites, except at FLY10 and TED35 which were monthly, however, historically, sampling was been erratic at many sites. In recent years, under the new Regime, sampling has been reduced to biannual, at FLY10, FLY14 and FLY20 only, with no other riverine and no floodplain sites sampled. All sampling was by the standard set of 13 gill-nets, ranging in stretched mesh size from 25 mm to 175 mm. At riverine sites, nets were tied at approximately 30⁰ to the bank in a series, each net separated from the next by a large enough distance to allow fish movements between the nets (usually >50 m). At floodplain sites, nets were set perpendicular to the bank, with the same spacing as riverine sites. Attempts were made to reset nets in the same locations at each site, but this was not always possible because of variability in river levels. Generally, at riverine sites, the nets were set in backwater areas, tied to the bank near the interface between the main current and the backwater. Heavy weights were used to anchor the outer end of the nets in position. The order in which nets were set was from larger nets at the downstream end of the series to smaller nets at the

upstream end. The nets were set for 24 hours and checked at dawn, dusk and the end of the sampling period.

3.2 Sample processing

All fish captured were identified to species, measured in length to the nearest 1 mm (fork or total length, depending on body shape) and weighed to the nearest 1 gram up to 6 kg and then to the nearest 100 g over 6 kg. When large numbers of a single species were caught in a net, a sub-sample of approximately 100 specimens was selected at random and measured individually. The remainder were counted and their total weight determined.

3.3 Temporal differences in community structure at key sites

Temporal changes in fish community structure were assessed for key, long term monitoring sites located along the length of the river and on the floodplain (Figure 1). Not all sites were sampled over the same time period, however, the longest data series for each site was selected for analysis (Table 1).

Table 1. Key long term monitoring sites with length of data series and number of samples taken from each site.

Site Name	Site Code	Start of Sampling	End of Sampling	No. of samples
<u>RIVERINE SITES</u>				
New Atkamba	TED35	January 1993	March 2002	73
Kuambit	FLY10	June 1983	October 2003	148
Bosset	FLY14	June 1983	February 2004	65
Obo	FLY15	April 1987	February 2002	53
Ogwa	FLY20	April 1987	February 2004	56
Strickland River	STR01	April 1987	February 2002	53
<u>FLOODPLAIN SITES</u>				
Bosset Lagoon	BOS10	June 1983	May 1996	55
Bosset Lagoon	BOS11	May 1991	March 2001	27
Daviumbu	DAV01	April 1987	February 2002	41
Sembe Oxbow	OXB03	October 1990	October 1998	28
Lake Pangua	OXB05	June 1989	February 2002	42
@ ARM345	OXB06	June 1993	March 2002	28
Strickland	OXB08	March 1992	February 2002	18

3.4 Analytical methods

Initial analyses followed the approach used by OTML (1994; 1995) to estimate changes in species richness, abundance and biomass at each site using linear regression, with time as the independent variable and each parameter of fish catch as the dependent variables. Data for abundance and biomass were $\ln(x+1)$ transformed to normalise the data prior to analysis; species richness was untransformed. For each site, observed changes in catch were plotted against time. Estimated catch values, as derived from the linear regression, with upper and lower 95 % confidence limits were then superimposed. For sites at which there was a significant linear relationship ($p < 0.05$) between time and each parameter, percentage change in the parameter was determined from the estimated data by calculating the difference between the means for the first and last sampling periods. The sampling periods were usually taken to be the first and last year over which data were collected. These analyses were undertaken to demonstrate if there were changes in community descriptors over time, which may

reflect a mine effects, and which would assist with interpretation of gradients in these parameters through the multivariate ordination plots.

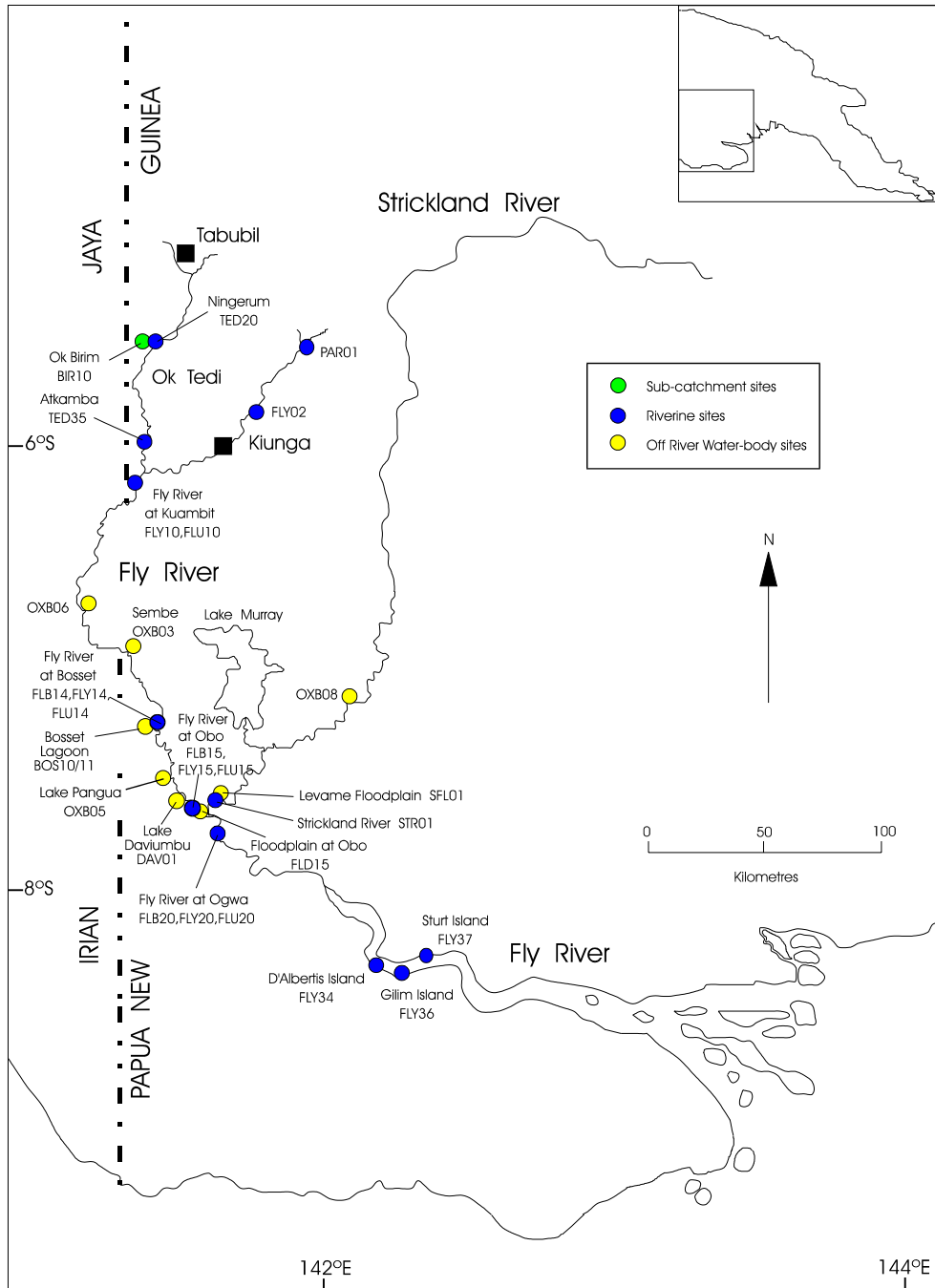


Figure 1. Location of riverine and floodplain sampling sites on the Fly River system

Data for each site were ordinated using the Semi-Strong Hybrid MultiDimensional Scaling (SSH MDS) program of the PATN software (Belbin, 1995). Analyses were performed using the abundance of each species at a site on each sampling occasion. Dissimilarity between sites/samples was determined using the Bray-Curtis dissimilarity coefficient, and species occurring in less than 10% of samples in any data set were omitted to avoid ‘rare’ species having a disproportionate effect on the analyses (Gauch, 1982). In several instances there were species complexes that were

taxonomically difficult to accurately differentiate in the field, therefore, these data were combined at the genus level (e.g. *Nematalosa flyensis* & *N. papuensis*).

To assess temporal changes, data for each site were subdivided into time periods corresponding to the different mine operating periods; data for copper flotation processing > 80,000 tpd, which extended over 10 years were split into two time periods of equal length, Cu>80k 1-5 yrs and Cu>80k 6-10 yrs (Table 2). Because sampling frequency at each site has not always been consistent over the duration of the life of the mine, there was not always the same number of samples in each time period (Table 2). Samples were grouped according to time periods and these groups illustrated on the ordinations.

The degree of separation between groups in ordination space were assessed visually, and statistically using the **Analysis of Similarity (ANOSIM)** procedure (Belbin, 1995). This technique compares the mean and variance of dissimilarities for samples within each group to between-group means and statistically tests for separation of groups using Monte-Carlo randomisations (n=100). For ordinations requiring three dimensions to achieve the optimum solution, plots were prepared using the two dimensions that demonstrated the greatest visual separation of groups in a 2-dimensional figure.

Table 2. Mine operating periods used to assess temporal changes in fish community structure at key monitoring sites, indicating the number of samples in each period from each site.

Site	Code	Time Periods				
		Baseline & gold only (Au)	Gold/copper & copper < 80,000 tpd (Au & Cu)	Copper > 80,000 tpd (1 - 5 yrs) (Cu>80k 5yr)	Copper > 80,000 tpd (6 - 10 yrs) (Cu<80k 10yr)	Dredge in operation (Dredge)
Start of period	End of period	December-83	August-87	August-89	September-93	March-98
		July-87	July-89	August-93	February-98	March-04
RIVERINE SITES						
New Atkamba	TED35			8	30	35
Kuambit	FLY10	14	9	43	49	33
Bosset	FLY14	14	7	14	14	16
Obo	FLY15		8	15	16	14
Ogwa	FLY20		9	15	16	16
Strickland R.	STR01		9	14	16	14
FLOODPLAIN SITES						
Bosset Lagoon	BOS10	14	7	15	10	9
Bosset Lagoon	BOS11			6	11	10
Daviumbu	DAV01		7	12	12	10
Sembe Oxbow	OXB03			12	12	4
Lake Pangua	OXB05			14	14	14
@ ARM345	OXB06			7	8	13
Strickland	OXB08			5	9	4

The Principal Axis Correlation (PCC) module of PATN (Belbin, 1995) was used to test for significant gradients in community descriptors (*viz.* species richness, abundance and biomass) through ordinations of each site. This module essentially performs a linear regression of each variable through the respective ordination of samples/sites. The significance of each gradient was tested using Monte-Carlo randomisations (n=100).

The technique identifies changes in species richness, abundance and biomass across ordination space, with the gradient indicating the direction of increasing values of the parameter. Gradients of time in days since sampling first commenced at each site (i.e. as an indication of cumulative exposure to mine effects), were also tested through

each ordination using PCC to assess presence of temporal changes in assemblages at each key monitoring site.

Finally, for temporal changes at each key monitoring site, changes in the frequency of occurrence of each species in each time period were tabulated and differences in occurrence between time periods tested by Chi-square contingency table analysis (Zar, 1974). The time period in which each species had the highest occurrence was ranked 1, with the time period with lowest occurrence ranked lowest. The significance of the level of occurrence between groups was reported, indicating the group that contributed most to the chi-square statistic, and therefore had the greatest change in occurrence.

4 Results

4.1 Temporal changes in community structure at riverine sites

4.1.1 New Atkamba (TED35) (January 1993 – March 2003)

Sampling at site New Atkamba (TED35) commenced in January 1993, as a replacement for Atkamba (TED30), which was cut-off in a meander loop. The short time period of sampling at New Atkamba dataset has limited the ability to reflect mine effects, particularly as the period of record covers only the copper flotation operating period (NB. data for Atkamba (TED30) were analysed by Storey (1997), and since no new data were collected at this site since it was last analysed – analyses were not repeated for TED30). However, the period of record does include before and after the commencement of dredging, and this site is the closest riverine site downstream of the dredge.

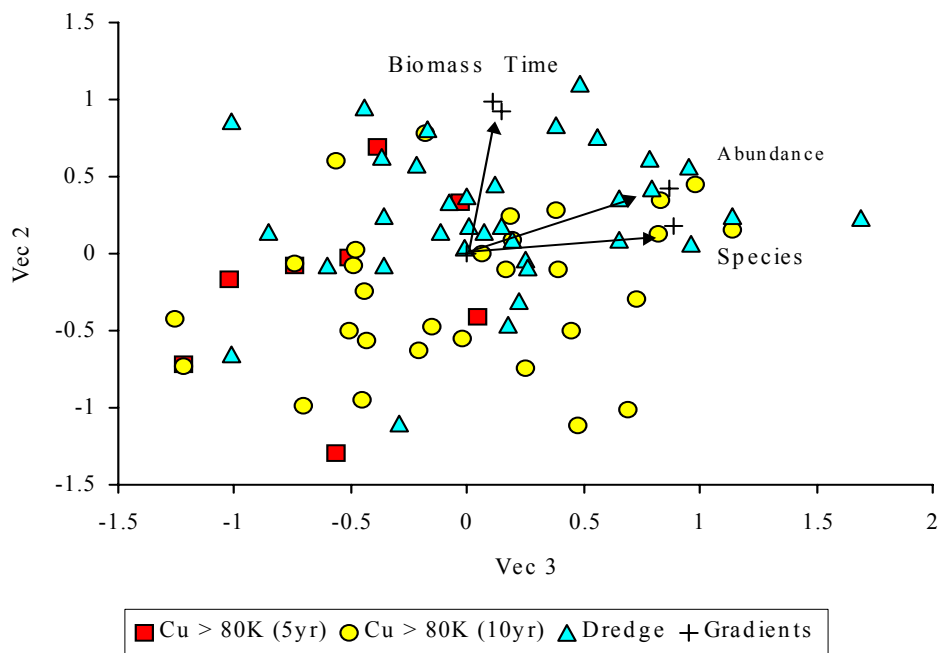


Figure 2 MDS ordination of New Atkamba (TED35) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with three dimensions and a stress of 0.1996).

Table 3 Species constancy in each time period for New Atkamba (TED35), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		3	4	5	Chi-square
Number of samples in each time period		8	30	35	significance
sp-10	Megalops cyprinoides	13	3	6	ns
sp-15	Clupeoides papuensis	13	17	11	ns
sp-18	Nematalosa spp	25	50	74	*
sp-20	Thryssa scratchleyi	0	10	14	ns
sp-21	Thryssa rastrosa	0	3	0	ns
sp-25	Scleropages jardini	0	7	3	ns
sp-30	Arius leptaspis	13	40	57	*
sp-31	Arius latirostris	13	27	6	ns
sp-32	Arius carinatus	25	10	0	*
sp-34	Arius berneyi	0	53	20	**
sp-35	Cinetodus crassilabris	0	3	0	ns
sp-36	Arius macrorhynchus	25	0	3	**
sp-37	Arius taylori	0	23	0	**
sp-38	Cinetodus froggatti	0	3	0	ns
sp-40	Cochlefelis spatula	38	47	34	ns
sp-50	Neosilurus ater	50	37	83	***
sp-51	Neosilurus equinus	0	0	6	ns
sp-56	Porochilus obbesi	13	13	14	ns
sp-58	Plotosus papuensis	25	3	3	*
sp-60	Craterocephalus randi	0	3	0	ns
sp-66	Liza alata (diadema)	0	7	11	ns
sp-70	Melanotaenia splendida	0	23	31	ns
sp-86	Strongylura krefftii	0	13	23	ns
sp-90	Zenarchopterus novaeguinae	13	7	6	ns
sp-95	Ambassis agrammus	13	30	31	ns
sp-98	Parambassis gulliveri	25	27	29	ns
sp-100	Lates calcarifer	25	17	9	ns
sp-105	Datnioides quadrifasciatus	13	7	11	ns
sp-111	Hephaestes raymondi	13	0	0	*
sp-113	Pingalla lorentzi	13	3	11	ns
sp-114	Amniataba percoides	0	13	14	ns
sp-115	Glossamia aprion	0	17	14	ns
sp-121	Lutjanus goldiei	0	10	11	ns
sp-130	Nibea semifasciata	25	7	3	ns
sp-135	Toxotes chatareus	13	17	14	ns
sp-140	Glossogobius giurus	0	3	3	ns
sp-143	Glossogobius concavifrons	0	3	0	ns
sp-148	Oxyeleotris lineolatus	13	3	0	ns
sp-161	Anabas testudineus	0	3	17	ns
sp-162	Clarias batrachus	0	0	6	ns
sp-168	Arius agreutes	0	3	0	ns
sp-170	Oxyeleotris herwerdini	13	10	26	ns
sp-186	Terapon lacustris	0	7	6	ns

Regression analyses did not detect significant change in species richness, abundance or biomass against time (Appendix 1a). However, ordination of samples from New Atkamba showed relatively good separation of samples from dredge and pre-dredge operating periods (Figure 2), with a significant separation of site groupings in ordination space (ANOSIM, $p < 0.0001$; Figure 2). Visually, samples collected after the commencement of dredging were separated from those collected prior to the commencement of dredging. Principal axis Correlation (PCC) detected significant gradients in species richness, abundance, biomass and time through the ordination plot, with all four parameters running in the approximate same direction, and towards samples collected after the start of dredging. This infers an increase in species richness, abundance and biomass with time, and may be interpreted as an

improvement in conditions at New Atkamba, possibly reflecting the influence of the dredge.

Chi-square contingency table analysis (Table 3) detected significant changes in the frequency of occurrence between time periods of nine of the 43 species. Of the nine species, three had a significant increase in occurrence with time (*Nematalosa*, *Arius leptaspis*, *Neosilurus ater*), indicating an increased presence of these species during dredging. *A. carinatus*, *A. macrorhynchus*, *Plotosus papuensis*, and *Hephaestes raymondi* all decreased in occurrence with time.

4.1.2 Kuambit (FLY10) (June 1983 – March 2003)

Regression analysis of species richness, abundance and biomass of fish against time detected significant declines in species richness ($p = 0.0110$; 22% reduction) and biomass ($p < 0.0001$, 79% reduction), but with no significant change in abundance of fish taken (Appendix 1b).

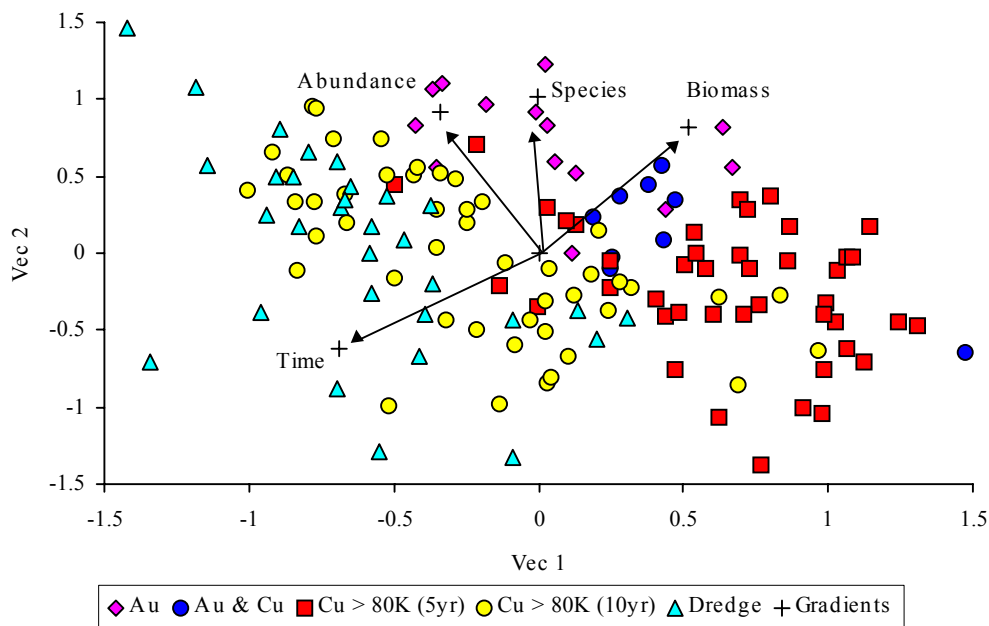


Figure 3 MDS ordination of Kuambit (FLY10) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with three dimensions and a stress of 0.1615).

Ordination of Kuambit data showed a significant separation of time periods (ANOSIM $p < 0.0001$; Figure 3) with a significant gradient in time ($p < 0.01$). Gradients in species diversity, biomass and abundance were all significant ($p < 0.01$). Gradients in biomass and species richness were approximately opposite in direction to the time gradient, whilst the abundance gradient was perpendicular to the time gradient. This indicates a greater reduction in biomass and species richness at this site over time, with not so strong a change in abundance of fish. Of the 59 species recorded from this site over the duration of sampling, 34 had significant changes in levels of occurrence between time periods (Table 4), the majority of which were showing declines with time.

Table 4. Species constancy in each time period for Kuambit (FLY10), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time Period	1	2	3	4	5	Chi-square significance	
Number of samples in each time period	14	9	43	49	33		
sp-10	Megalops cyprinoides	14	22	28	29	9	ns
sp-15	Clupeoides papuensis	21	11	0	16	9	ns
sp-18	Nematalosa spp	100	89	51	92	94	***
sp-20	Thryssa scratchleyi	100	100	30	51	64	***
sp-21	Thryssa rastroso	21	11	19	2	0	**
sp-25	Scleropages jardini	50	11	23	14	6	**
sp-30	Arius leptaspis	86	89	91	82	94	ns
sp-31	Arius latirostris	100	100	63	55	33	***
sp-32	Arius carinatus	71	56	37	20	18	**
sp-33	Arius augustus	79	11	26	0	0	***
sp-34	Arius berneyi	93	89	77	86	73	ns
sp-35	Cinetodus crassilabris	29	44	28	12	3	**
sp-36	Arius macrorhynchus	86	78	58	35	12	***
sp-37	Arius taylori	0	11	19	12	3	ns
sp-38	Cinetodus froggatti	57	11	7	2	3	***
sp-39	Nedystoma dayi	36	22	5	16	9	*
sp-40	Cochlefelis spatula	71	78	84	53	42	**
sp-41	Cochlefelis danielsi	14	11	7	4	3	ns
sp-50	Neosilurus ater	79	33	49	78	88	***
sp-51	Neosilurus equinus	0	0	0	0	3	ns
sp-52	Neosilurus sp.C	0	11	2	2	0	ns
sp-55	Oloplotosus luteus	0	0	2	0	0	ns
sp-56	Porochilus obbesi	0	0	5	41	52	***
sp-57	Porochilus meraukensis	29	0	0	4	3	***
sp-58	Plotosus papuensis	0	0	0	2	3	ns
sp-60	Craterocephalus randi	0	0	0	16	9	*
sp-65	Crenimugil labiosus	7	0	5	6	6	ns
sp-66	Liza alata (diadema)	43	22	40	18	9	*
sp-70	Melanotaenia splendida	14	0	7	37	21	**
sp-86	Strongylura krefftii	71	33	21	71	82	***
sp-90	Zenarchopterus novaeguinae	7	0	0	10	3	ns
sp-95	Ambassis agrammus	7	0	12	47	42	***
sp-98	Parambassis gulliveri	100	100	60	47	55	***
sp-100	Lates calcarifer	93	100	100	88	52	***
sp-105	Datnioides quadrifasciatus	14	11	12	14	3	ns
sp-110	Hephaestes roemeri	14	11	5	10	3	ns
sp-113	Pingalla lorentzi	21	0	2	31	15	**
sp-114	Amniataba percoides	7	0	5	16	30	*
sp-115	Glossamia aprion	0	11	9	37	27	**
sp-116	Glossamia trifasciata	0	0	2	0	0	ns
sp-120	Lutjanus argentimaculatus	7	0	0	0	0	*
sp-121	Lutjanus goldiei	43	67	40	39	15	*
sp-125	Acanthopagrus berda	29	0	0	0	0	***
sp-130	Nibea semifasciata	43	11	40	18	27	ns
sp-135	Toxotes chatareus	86	44	23	51	61	**
sp-140	Glossogobius giurus	0	0	0	4	0	ns
sp-142	Glossogobius sp.	0	0	0	2	9	ns
sp-145	Mogurnda mogurnda	0	0	0	0	3	ns
sp-146	Oxyeleotris fimbriata	14	0	14	6	3	ns
sp-148	Oxyeleotris lineolatus	14	0	14	18	0	ns
sp-150	Kurtus gulliveri	71	11	7	2	0	***
sp-161	Anabas testudineus	0	0	7	18	33	**
sp-162	Clarias batrachus	0	0	0	0	15	*
sp-170	Oxyeleotris herwerdini	0	0	0	29	48	***
sp-171	Mogurnda cingulata	0	0	2	0	0	ns
sp-181	Liza subviridis	0	0	0	2	0	ns
sp-186	Terapon lacustris	0	0	0	10	39	***
sp-190	Ambassis spp	0	0	2	0	0	ns
sp-191	Hephaestes fuliginosus	0	0	0	2	0	ns

Species such as *Scleropages jardini*, *Arius latirostris*, *Arius carinatus*, *Cinetodus crassilabris*, *Arius macrorhynchus*, *Cinetodus froggatti*, *Cochlefelis spatula*, *Liza alata (diadema)* and *Lates calcarifer* have declined in occurrence over time, but still occasionally occur. Three species have not been recorded at the site in the last one to two time periods; *Thryssa rastrosa*, *Arius augustus* and *Kurtus gulliveri*, and appear to have been lost from the site. There were also a range of other species that occurred only occasionally, but tended to be recorded in earlier years and have not been taken in recent years, but had too low a frequency to allow meaningful statistical analysis (Table 4).

4.1.3 Bosset (FLY14) (June 1983 – March 2003)

Regression of community parameters against time detected significant declines in species richness ($p = 0.0001$; 46% reduction), abundance ($p = 0.0001$, 79% reduction), and biomass ($p < 0.0001$, 75% reduction) over time (Appendix 1c), indicative of significant changes at this site over time. These changes were reflected in changes in fish assemblages.

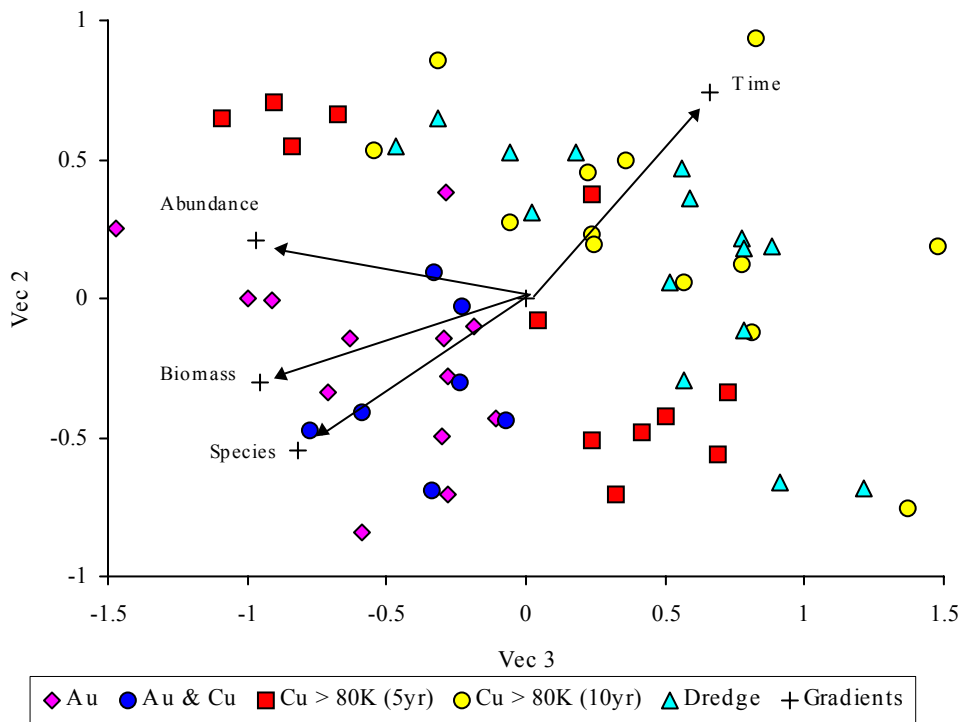


Figure 4 MDS ordination of Fly River at Bosset (FLY14) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with three dimensions and a stress of 0.1655).

Ordination of Bosset data showed a significant separation of time periods in ordination space (ANOSIM $p < 0.0001$; Figure 4) with a significant gradient in time ($p < 0.01$). The first three time periods (Au, Au/Cu and Cu < 80k) showed little separation, but the two most recent time periods (Cu > 80k and Dredge) separated from the earlier time periods (Figure 2), with a significant time gradient in the

direction of the more recent time periods. Gradients in species richness, biomass and abundance were all significant ($p < 0.01$) and were in the opposite direction to the time gradient, indicating declines in these parameters over time. These patterns are reflected in the regression analysis of community descriptors against time (Appendix 1c).

Chi-square contingency table analysis detected significant changes in the levels of occurrence of 19 of the 54 species between time periods (Table 5), the majority of which were showing declines with time. Five species have not been recorded at the site in the last time period (*Pristis microdon*, *Thryssa rastroso*, *Arius latirostris*, *Cinetodus crassilabris*, *Nedystoma dayi*), and an additional three species which were frequently taken in the past have been recorded only once in the last 16 gill net sets (*Megalops cyprinoides*, *Arius carinatus*, *Arius augustus*). *Lutjanus argentimaculatus* and *Oxyeleotris lineolatus* also appear to have declined over time, however, *L. goldeii* and *O. herwerdenii*, which are morphologically similar have increased in occurrence over time suggesting the these pairs of species are not being correctly identified in the field.

Interestingly, species such as *A. augustus* and *S. rastroso*, which have declined in the Fly River at Bosset, have also declined in the Fly River at Kuambit, which supports the contention of a mine-related impact in the Fly River at Bosset.

Table 5. Species constancy in each time period for Bosset (FLY14), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time Period	1	2	3	4	5	Chi-square significance	
Number of samples in each time period	14	7	14	14	16		
sp-1	Pristis microdon	64	14	0	0	0	***
sp-10	Megalops cyprinoides	86	71	57	50	6	***
sp-15	Clupeoides papuensis	0	14	0	0	0	ns
sp-18	Nematalosa spp	100	100	93	100	88	ns
sp-20	Thryssa scratchleyi	100	86	79	71	88	ns
sp-21	Thryssa rastrosa	29	43	21	43	0	*
sp-25	Scleropages jardini	64	100	71	43	56	ns
sp-30	Arius leptaspis	93	100	100	93	100	ns
sp-31	Arius latirostris	7	43	7	21	0	*
sp-32	Arius carinatus	71	100	43	29	6	***
sp-33	Arius augustus	50	71	14	0	6	***
sp-34	Arius berneyi	93	100	93	100	100	ns
sp-35	Cinetodus crassilabris	14	43	14	0	0	*
sp-36	Arius macrorhynchus	100	100	64	7	31	***
sp-38	Cinetodus froggatti	71	43	21	7	13	**
sp-39	Nedystoma dayi	29	0	0	7	0	*
sp-40	Cochlefelis spatula	64	71	64	7	19	***
sp-41	Cochlefelis danielsi	57	57	29	14	25	ns
sp-50	Neosilurus ater	100	100	86	71	88	ns
sp-55	Oloplotosus luteus	0	14	0	0	0	ns
sp-56	Porochilus obbesi	43	43	43	21	44	ns
sp-57	Porochilus meraukensis	0	0	0	43	0	***
sp-58	Plotosus papuensis	7	0	0	0	0	ns
sp-59	Porochilus spp	0	0	0	7	0	ns
sp-65	Crenimugil labiosus	7	0	0	0	0	ns
sp-66	Liza alata (diadema)	93	100	93	36	50	***
sp-70	Melanotaenia splendida	7	0	0	7	13	ns
sp-86	Strongylura krefftii	100	71	71	93	88	ns
sp-95	Ambassis agrammus	7	0	14	21	13	ns
sp-98	Parambassis gulliveri	64	43	79	43	69	ns
sp-100	Lates calcarifer	100	100	100	93	88	ns
sp-105	Datnioides quadrifasciatus	71	71	50	36	25	ns
sp-110	Hephaestes roemeri	0	0	7	0	6	ns
sp-113	Pingalla lorentzi	0	0	0	0	6	ns
sp-114	Amniataba percoides	21	0	14	7	19	ns
sp-115	Glossamia aprion	21	14	7	0	25	ns
sp-120	Lutjanus argentimaculatus	14	29	7	0	0	ns
sp-121	Lutjanus goldiei	29	71	79	43	44	ns
sp-125	Acanthopagrus berda	14	14	7	0	0	ns
sp-130	Nibea semifasciata	57	86	50	21	25	*
sp-135	Toxotes chatareus	86	71	93	79	63	ns
sp-136	Toxotes lorentzi	29	0	7	0	0	*
sp-138	Scatophagus argus	0	0	7	0	6	ns
sp-146	Oxyeleotris fimbriata	21	14	64	0	0	***
sp-148	Oxyeleotris lineolatus	29	14	21	0	0	ns
sp-150	Kurtus gulliveri	29	14	0	14	0	ns
sp-161	Anabas testudineus	0	0	29	64	75	***
sp-162	Clarias batrachus	0	0	0	14	13	*
sp-170	Oxyeleotris herwerdini	0	0	0	29	6	*
sp-172	Oxyeleotris spp	0	0	7	0	0	ns
sp-181	Liza subviridis	0	0	7	0	0	ns
sp-186	Terapon lacustris	29	14	29	21	31	ns
sp-189	Ambassis macleayi	0	0	0	0	6	ns
sp-191	Hephaestes fuliginosus	0	0	7	0	0	ns

4.1.4 Obo (FLY15) (April 1987 – February 2002)

Regression of community descriptors against time detected significant declines in species richness ($p = 0.0001$; 35% reduction), abundance ($p = 0.042$, 56% reduction), and biomass ($p = 0.0008$, 57% reduction) over time (Appendix 1d).

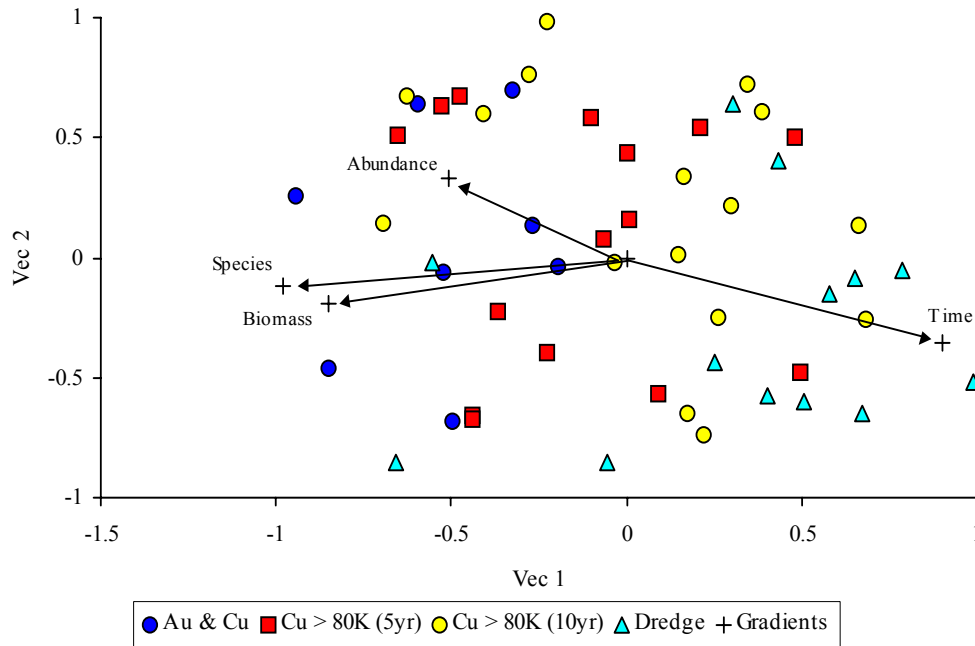


Figure 5 MDS ordination of Fly River at Obo (FLY15) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with three dimensions and a stress of 0.1680).

Ordination of data for the Fly River at Obo showed a significant separation of time periods (ANOSIM $p < 0.0001$; Figure 5) with a significant gradient in time ($p < 0.01$) through ordination space. As for the ordination of data from the Fly River at Bosset, the later time periods, particularly the most recent periods (Cu>80k & Dredge) showed the greatest separation, with the other periods generally overlapping. Gradients in species diversity, biomass and abundance were all significant ($p < 0.01$) and in the opposite direction to the time gradient. This indicates decreases in these parameters over time, and supports the linear regressions of these parameters against time. Chi-square analysis detected significant changes in the occurrence of 11 of the 45 species between time periods (Table 5), the majority of which were showing declines with time. Four species have not been recorded at the site in the last time period (*Pristis microdon*, *Arius augustus*, *Cinetodus crassilabris*, *Cinetodus froggatti*), and six species have been recorded only once in the last 10 gill net sets. As for Bosset, there seems to be confusion over the field identification of *Lutjanus argentimaculatus* and *L. goldeii*, and between *Oxyeleotris lineolatus* and *O. herwerdeni*. Declines in these species probably reflect mis-identifications. As for fish assemblages in the Fly at Kuambit and Bosset, the same groups of species appear to be in decline or have been lost from the Fly at Obo.

Table 6. Species constancy in each time period for Fly at Obo (FLY15), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, p<0.05, ** p<0.01, *** p<0.001). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		2	3	4	5	Chi-square
Number of samples in each time period		8	15	16	14	significance
sp-1	Pristis microdon	50	0	6	0	***
sp-10	Megalops cyprinoides	88	67	31	43	*
sp-15	Clupeoides papuensis	13	7	6	0	ns
sp-18	Nematalosa spp	100	100	88	93	ns
sp-20	Thryssa scratchleyi	100	100	88	79	ns
sp-21	Thryssa rastrosa	38	47	6	7	*
sp-25	Scleropages jardini	75	87	56	50	ns
sp-30	Arius leptaspis	100	93	100	100	ns
sp-31	Arius latirostris	13	13	0	7	ns
sp-32	Arius carinatus	88	47	44	29	ns
sp-33	Arius augustus	38	33	6	0	*
sp-34	Arius berneyi	100	93	75	100	ns
sp-35	Cinetodus crassilabris	25	47	6	0	**
sp-36	Arius macrorhynchus	88	53	44	21	*
sp-38	Cinetodus froggatti	38	7	19	0	*
sp-39	Nedystoma dayi	13	0	6	0	ns
sp-40	Cochlefelis spatula	75	33	38	29	ns
sp-41	Cochlefelis danielsi	88	53	50	29	ns
sp-50	Neosilurus ater	100	80	88	86	ns
sp-56	Porochilus obbesi	25	33	56	14	ns
sp-66	Liza alata (diadema)	88	93	69	43	*
sp-70	Melanotaenia splendida	25	0	13	43	*
sp-86	Strongylura krefftii	88	87	31	79	**
sp-95	Ambassis agrammus	0	7	6	21	ns
sp-98	Parambassis gulliveri	50	60	31	50	ns
sp-100	Lates calcarifer	100	100	88	93	ns
sp-105	Datnioides quadrifasciatus	50	33	19	14	ns
sp-110	Hephaestes roemeri	0	0	0	7	ns
sp-114	Amniataba percoides	0	33	31	29	ns
sp-115	Glossamia aprion	0	13	19	7	ns
sp-120	Lutjanus argentimaculatus	25	0	0	0	**
sp-121	Lutjanus goldiei	38	67	56	36	ns
sp-125	Acanthopagrus berda	25	13	6	0	ns
sp-130	Nibea semifasciata	38	47	19	7	ns
sp-135	Toxotes chatareus	50	67	63	79	ns
sp-136	Toxotes lorentzi	13	7	0	0	ns
sp-138	Scatophagus argus	25	7	6	0	ns
sp-145	Mogurnda mogurnda	13	0	6	7	ns
sp-146	Oxyeleotris fimbriata	13	13	0	0	ns
sp-147	Oxyeleotris nullipora	13	0	0	0	ns
sp-148	Oxyeleotris lineolatus	13	13	6	0	ns
sp-161	Anabas testudineus	25	40	56	57	ns
sp-162	Clarias batrachus	0	0	13	29	ns
sp-170	Oxyeleotris herwerdini	0	0	13	14	ns
sp-186	Terapon lacustris	13	7	25	21	ns

4.1.5 Ogwa (FLY20) (April 1987 – March 2003)

Regression of species richness, abundance and biomass against time detected a significant decline in species richness ($p = 0.0048$; 21% reduction), but no significant changes in abundance or biomass over time (Appendix 1e).

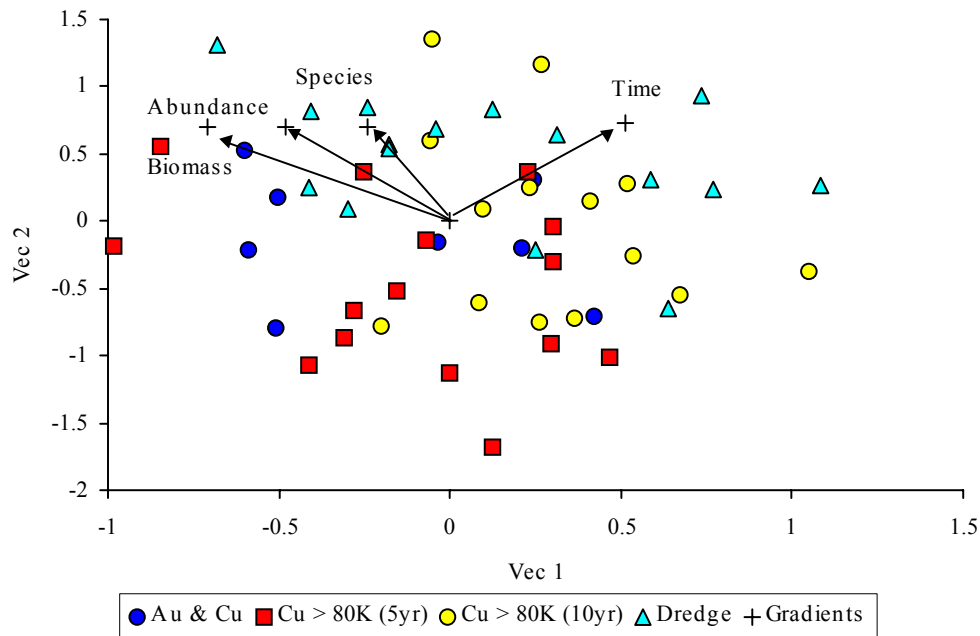


Figure 6 MDS ordination of Fly River at Ogwa (FLY20) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with three dimensions and a stress of 0.1904).

Ordination of Ogwa data showed a significant separation of time periods (ANOSIM $p < 0.0001$; Figure 6) with a significant gradient in time ($p < 0.01$). There was considerable overlap between samples from successive time periods, however, the first (Au & Cu) and last time periods (Dredge) were not overlapping which would have been sufficient to give the significant separation of groups. Gradients in species diversity, biomass and abundance were all significant ($p < 0.01$) but not directly opposite to the time gradient indicating lesser changes in these parameters over time than at highly impacted sites (*viz.* New Atkamba, Kuambit and Bosset). Eight of the 52 species recorded from this site showed significant changes in their levels of occurrence between time periods (Table 7). Two species have not been recorded at Ogwa in the last time period (*Thryssa rastroso*, *Arius latirostris*), and three species are showing signs of early stages of decline (*Arius carinatus*, *Arius augustus*, *Cinetodus crassilabris*). These species have either been lost from upstream sites or are in decline, suggesting effects observed at upstream sites may be progressing further downstream.

Table 7. Species constancy in each time period for Fly at Ogwa (FLY20), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		2	3	4	5	Chi-square
Number of samples in each time period		9	15	16	16	significance
sp-1	Pristis microdon	78	47	38	38	ns
sp-10	Megalops cyprinoides	56	47	69	44	ns
sp-18	Nematalosa spp	78	67	75	88	ns
sp-20	Thryssa scratchleyi	89	100	100	88	ns
sp-21	Thryssa rastrosa	44	13	0	0	**
sp-22	Thryssa spp	0	7	0	0	ns
sp-25	Scleropages jardini	67	60	44	63	ns
sp-30	Arius leptaspis	89	93	94	88	ns
sp-31	Arius latirostris	33	0	25	0	*
sp-32	Arius carinatus	78	80	44	19	**
sp-33	Arius augustus	100	100	94	75	*
sp-34	Arius berneyi	33	53	56	69	ns
sp-35	Cinetodus crassilabris	22	47	6	6	*
sp-36	Arius macrorhynchus	100	60	38	75	*
sp-38	Cinetodus froggatti	56	60	44	38	ns
sp-39	Nedystoma dayi	11	0	0	0	ns
sp-40	Cochlefelis spatula	89	93	94	81	ns
sp-41	Cochlefelis danielsi	100	93	100	88	ns
sp-50	Neosilurus ater	67	67	75	75	ns
sp-56	Porochilus obbesi	44	7	50	25	*
sp-58	Plotosus papuensis	11	0	0	0	ns
sp-66	Liza alata (diadema)	78	87	75	88	ns
sp-68	Liza macrolepis	0	0	0	6	ns
sp-70	Melanotaenia splendida	11	0	0	6	ns
sp-86	Strongylura krefftii	33	47	38	25	ns
sp-90	Zenarchopterus novaeguinae	11	0	0	0	ns
sp-95	Ambassis agrammus	22	0	0	0	*
sp-98	Parambassis gulliveri	44	33	38	56	ns
sp-100	Lates calcarifer	100	100	100	100	ns
sp-105	Datnioides quadrifasciatus	67	47	31	19	ns
sp-113	Pingalla lorentzi	0	7	0	0	ns
sp-114	Amniataba percoides	0	0	0	13	ns
sp-115	Glossamia aprion	0	0	0	13	ns
sp-120	Lutjanus argentimaculatus	22	7	0	0	ns
sp-121	Lutjanus goldiei	44	67	75	75	ns
sp-125	Acanthopagrus berda	11	20	0	6	ns
sp-130	Nibea semifasciata	78	47	75	56	ns
sp-135	Toxotes chatareus	67	33	38	75	ns
sp-136	Toxotes lorentzi	11	0	0	0	ns
sp-138	Scatophagus argus	22	0	6	19	ns
sp-146	Oxyeleotris fimbriata	11	0	0	0	ns
sp-147	Oxyeleotris nullipora	11	0	0	0	ns
sp-148	Oxyeleotris lineolatus	11	13	13	0	ns
sp-150	Kurtus gulliveri	22	27	31	13	ns
sp-161	Anabas testudineus	22	13	25	38	ns
sp-162	Clarias batrachus	0	0	0	6	ns
sp-163	Ophieleotris aporos	11	0	6	0	ns
sp-164	Tetranesodon conorhynchus	0	7	0	0	ns
sp-168	Arius agreutes	0	7	0	0	ns
sp-170	Oxyeleotris herwerdini	0	0	13	13	ns
sp-184	Carcharhinus leucas	0	7	0	0	ns
sp-186	Terapon lacustris	11	0	6	6	ns

4.1.6 Strickland River (STR01) (April 1987 – February 2002)

Regression of species richness, abundance and biomass against time detected a significant decline in biomass ($p = 0.0075$; 49% reduction), but no significant changes in species richness or abundance (Appendix 1f).

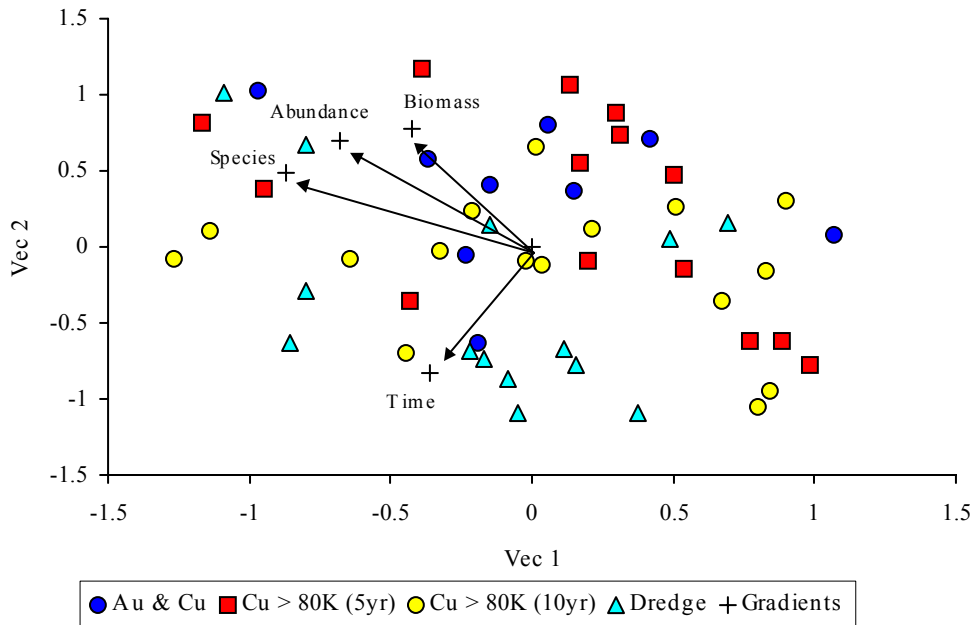


Figure 7 MDS ordination of Strickland River (STR01) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with three dimensions and a stress of 0.1793).

Ordination of Strickland River data showed a significant separation of time periods (ANOSIM $p < 0.0001$; Figure 7) with a significant gradient in time ($p < 0.01$). As for analysis from Ogwa, there was considerable overlap between samples from successive time periods, however, there was minimal overlap between the first and last time periods which would have been sufficient to give the significant separation of groups. Gradients in species diversity, biomass and abundance were all significant ($p < 0.01$) but not directly opposite to the time gradient. This indicates lesser changes in these parameters over time than at impacted sites. Four of the 47 species taken from this site showed changed levels of occurrence across time periods (Table 8), but one of these was *L. argentimaculatus*, and *L. goldei* was still common, possibly indicating confusion in identifications.

Table 8. Species constancy in each time period for Strickland River (STR01), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		2	3	4	5	Chi-square
Number of samples in each time period		9	14	16	14	significance
sp-1	Pristis microdon	56	43	31	14	ns
sp-10	Megalops cyprinoides	11	29	13	29	ns
sp-15	Clupeoides papuensis	11	0	0	0	ns
sp-18	Nematalosa spp	44	29	31	43	ns
sp-20	Thryssa scratchleyi	100	71	94	86	ns
sp-21	Thryssa rastrosa	11	0	0	0	ns
sp-25	Scleropages jardini	22	14	6	29	ns
sp-30	Arius leptaspis	56	57	88	93	*
sp-31	Arius latirostris	11	0	6	0	ns
sp-32	Arius carinatus	89	79	75	29	**
sp-33	Arius augustus	100	100	100	93	ns
sp-34	Arius berneyi	22	14	13	0	ns
sp-35	Cinetodus crassilabris	33	79	6	7	***
sp-36	Arius macrorhynchus	100	93	94	79	ns
sp-37	Arius taylori	11	0	6	0	ns
sp-38	Cinetodus froggatti	44	50	31	14	ns
sp-39	Nedystoma dayi	11	0	6	0	ns
sp-40	Cochlefelis spatula	89	71	81	64	ns
sp-41	Cochlefelis danielsi	89	79	75	86	ns
sp-50	Neosilurus ater	22	43	19	29	ns
sp-56	Porochilus obbesi	11	14	44	21	ns
sp-57	Porochilus meraukensis	0	7	0	0	ns
sp-66	Liza alata (diadema)	56	71	56	64	ns
sp-86	Strongylura krefftii	22	21	19	21	ns
sp-95	Ambassis agrammus	0	0	6	14	ns
sp-98	Parambassis gulliveri	22	50	50	50	ns
sp-100	Lates calcarifer	89	100	88	100	ns
sp-105	Datnioides quadrifasciatus	33	14	6	7	ns
sp-114	Amniataba percoides	0	7	6	0	ns
sp-115	Glossamia aprion	0	0	0	14	ns
sp-120	Lutjanus argentimaculatus	22	0	0	0	*
sp-121	Lutjanus goldiei	33	50	56	64	ns
sp-125	Acanthopagrus berda	11	7	0	0	ns
sp-130	Nibea semifasciata	67	71	44	79	ns
sp-135	Toxotes chatareus	22	36	31	14	ns
sp-136	Toxotes lorentzi	0	7	0	0	ns
sp-146	Oxyeleotris fimbriata	22	14	0	0	ns
sp-147	Oxyeleotris nullipora	11	0	0	0	ns
sp-148	Oxyeleotris lineolatus	0	14	0	0	ns
sp-150	Kurtus gulliveri	11	7	13	7	ns
sp-161	Anabas testudineus	0	7	13	36	ns
sp-162	Clarias batrachus	0	0	6	14	ns
sp-164	Tetranesodon conorhynchus	0	14	0	0	ns
sp-167	Arius sp.A	0	7	0	0	ns
sp-168	Arius agreutes	11	14	0	0	ns
sp-170	Oxyeleotris herwerdini	0	0	13	21	ns
sp-186	Terapon lacustris	0	7	6	0	ns

4.2 Temporal changes in community structure at floodplain sites

4.2.1 Bosset Lagoon (BOS10) (June 1983 – May 1996)

Regression of species richness, abundance and biomass against time detected a significant decline in species richness ($p = 0.0112$; 32% reduction) and biomass ($p = 0.0021$; 72% reduction), but no significant changes in abundance in Bosset Lagoon over time (Appendix 1g).

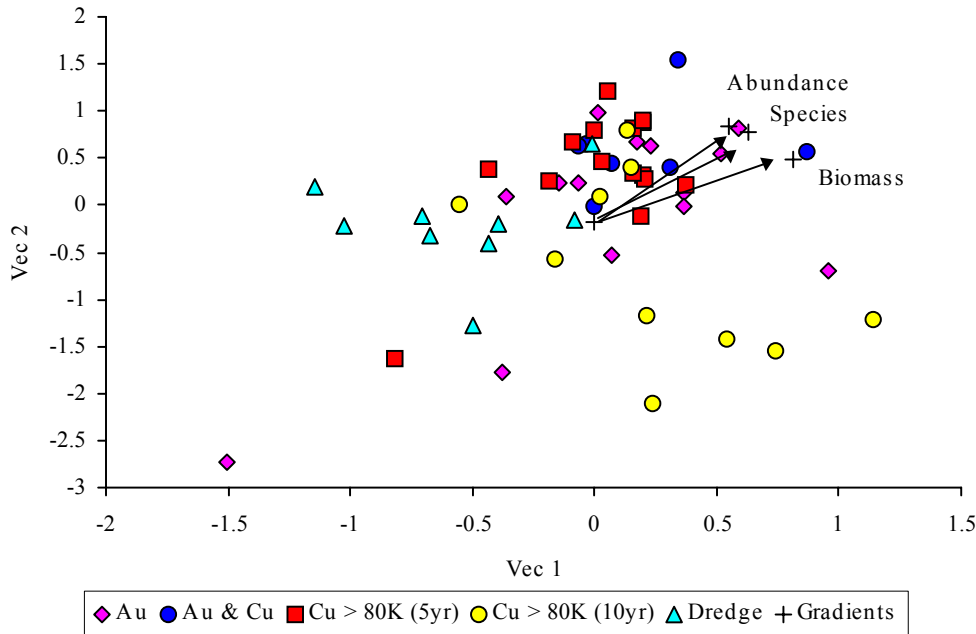


Figure 8 MDS ordination of Bosset Lagoon (BOS10) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with two dimensions and a stress of 0.1350).

Ordination of Bosset Lagoon data showed a significant separation of periods in ordination space (ANOSIM $p < 0.0001$; Figure 8), however the gradient in time was not significant ($p > 0.05$) indicating temporal changes were not great. There was considerable overlap between samples from successive time periods however, there was minimal overlap between the earliest time periods and the latest periods (Cu > 80k & Dredge). This separation would be sufficient to give the significant separation of groups. Gradients in species diversity, biomass and abundance were all significant ($p < 0.01$), but did not reflect declines over time, but rather separation of groupings of sites with high abundance, species richness and biomass from those with low values. This indicates lesser changes in these parameters over time than at riverine sites. Sixteen of the 40 species taken from this site showed changed levels of occurrence across time periods, with eight species declining with time (Table 9), one of which was *Oxyeleotris lineolatus*, but *O. herwerdini* increased in occurrence, possibly indicating confusion in identification between these two species. A group of other species demonstrated declines in occurrence in the mid 1990s, probably reflecting effects of El Nino droughts on Bosset Lagoon, which dried at various times (i.e. *Nematalosa* spp., *Strongylura krefftii*, *Glossamia aprion*).

Table 9. Species constancy in each time period for Bosset Lagoon (BOS10), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, p<0.05, ** p<0.01, *** p<0.001). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		1	2	3	4	5	Chi-square
Number of samples in each time period		14	7	15	10	9	significance
sp-1	Pristis microdon	21	0	0	0	0	*
sp-10	Megalops cyprinoides	71	86	60	30	56	ns
sp-18	Nematalosa spp	86	100	100	60	100	*
sp-20	Thryssa scratchleyi	79	100	33	0	11	***
sp-21	Thryssa rastroso	57	57	40	0	0	**
sp-22	Thryssa spp	0	0	7	0	0	ns
sp-25	Scleropages jardini	64	71	67	100	33	*
sp-30	Arius leptaspis	93	100	100	80	89	ns
sp-33	Arius augustus	0	14	0	0	0	ns
sp-34	Arius berneyi	79	100	80	70	89	ns
sp-38	Cinetodus froggatti	50	0	7	0	0	***
sp-40	Cochlefelis spatula	0	0	13	0	0	ns
sp-50	Neosilurus ater	93	100	100	100	89	ns
sp-53	Neosilurus brevidorsalis	0	0	7	0	0	ns
sp-56	Porochilus obbesi	86	71	60	30	44	ns
sp-57	Porochilus meraukensis	0	0	0	60	22	***
sp-58	Plotosus papuensis	14	29	0	0	0	ns
sp-66	Liza alata (diadema)	21	29	33	0	0	ns
sp-70	Melanotaenia splendida	7	14	7	40	33	ns
sp-86	Strongylura krefftii	86	100	93	50	100	**
sp-95	Ambassis agrammus	36	57	40	20	67	ns
sp-97	Denarius bandata	7	0	0	0	0	ns
sp-98	Parambassis gulliveri	29	14	7	0	0	ns
sp-100	Lates calcarifer	64	0	33	0	22	**
sp-105	Datnioides quadrifasciatus	7	14	7	0	0	ns
sp-113	Pingala lorentzi	0	0	20	0	0	ns
sp-114	Amniataba percoides	50	43	80	0	33	**
sp-115	Glossamia aprion	64	43	87	30	44	*
sp-120	Lutjanus argentimaculatus	0	14	7	0	0	ns
sp-121	Lutjanus goldiei	0	0	7	0	0	ns
sp-135	Toxotes chatareus	71	100	93	90	89	ns
sp-136	Toxotes lorentzi	43	14	13	0	0	*
sp-146	Oxyeleotris fimbriata	100	71	47	0	0	***
sp-148	Oxyeleotris lineolatus	36	57	60	0	0	**
sp-150	Kurtus gulliveri	7	0	0	0	0	ns
sp-161	Anabas testudineus	0	14	80	100	22	***
sp-162	Clarias batrachus	0	0	0	10	0	ns
sp-170	Oxyeleotris herwerdini	0	0	20	100	67	***
sp-186	Terapon lacustris	71	57	47	60	44	ns
sp-189	Ambassis macleayi	0	0	0	10	11	ns

4.2.2 Bosset Lagoon (BOS11) (May 1991 – March 2001)

The data set for Bosset Lagoon site BOS11 consists of 27 samples collected over a 10 year period from May 1991 to March 2001, and only covers two mine periods, Cu>80k and Dredge. Regressions of species richness, abundance and biomass against time failed to detect any significant declines (Appendix 1h), reflecting the relatively short sampling period.

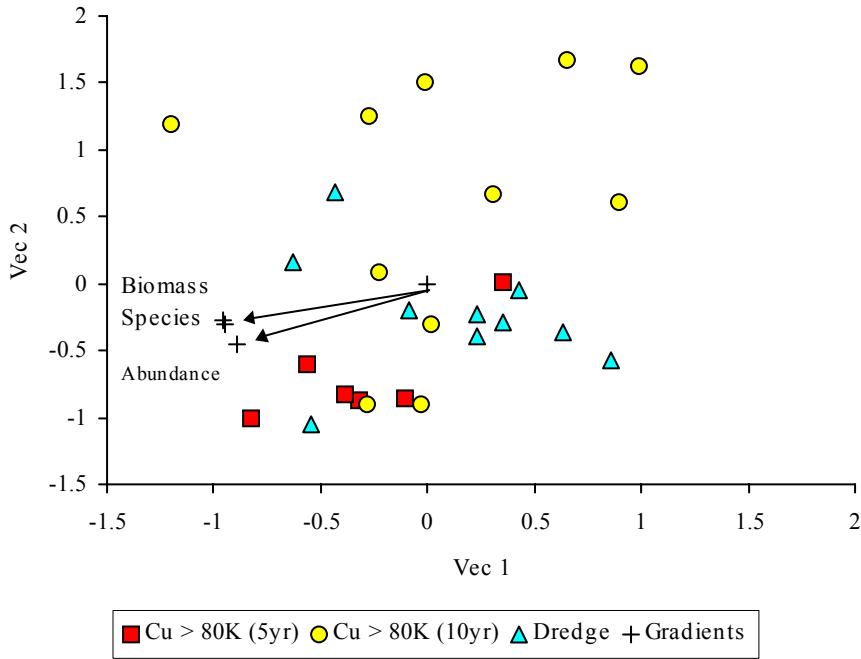


Figure 9 MDS ordination of Bosset Lagoon (BOS11) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with two dimensions and a stress of 0.1418).

Table 10. Species constancy in each time period for Bosset Lagoon (BOS11), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		3	4	5	Chi-square
Number of samples in each time period		6	11	10	significance
sp-10	Megalops cyprinoides	17	9	40	ns
sp-18	Nematalosa spp	100	55	100	*
sp-20	Thryssa scratchleyi	33	0	0	*
sp-21	Thryssa rastroso	17	9	0	ns
sp-22	Thryssa spp	17	0	0	ns
sp-25	Scleropages jardini	33	82	40	ns
sp-30	Arius leptaspis	100	100	100	ns
sp-34	Arius berneyi	100	45	80	*
sp-50	Neosilurus ater	100	91	90	ns
sp-56	Porochilus obbesi	67	18	70	*
sp-57	Porochilus meraukensis	0	73	20	**
sp-70	Melanotaenia splendida	17	27	30	ns
sp-86	Strongylura krefftii	100	64	100	*
sp-95	Ambassis agrammus	17	18	40	ns
sp-98	Parambassis gulliveri	0	9	0	ns
sp-100	Lates calcarifer	17	0	10	ns
sp-113	Pingala lorentzi	17	0	0	ns
sp-114	Amniataba percoides	83	0	20	***
sp-115	Glossamia aprion	83	45	80	ns
sp-135	Toxotes chatareus	83	27	60	ns
sp-136	Toxotes lorentzi	17	18	0	ns
sp-146	Oxyeleotris fimbriata	33	0	0	*
sp-148	Oxyeleotris lineolatus	83	0	0	***
sp-161	Anabas testudineus	67	45	30	ns
sp-162	Clarias batrachus	0	9	20	ns
sp-170	Oxyeleotris herwerdini	33	82	80	ns
sp-186	Terapon lacustris	83	36	70	ns
sp-189	Ambassis macleayi	0	0	30	ns

Ordination of samples from site BOS11 showed no clear separation of samples according to time periods (ANOSIM > 0.05), with considerable overlap in samples from successive time periods (Figure 9). The gradient in time was not significant ($p > 0.05$) indicating temporal changes were not great. Gradients in species diversity, biomass and abundance through ordination space were all significant ($p < 0.01$), but did not reflect declines over time, but rather separation of groupings of sites with high abundance, species richness and biomass from those with low values (Figure 9). This indicates lesser changes in these parameters over time than at riverine sites. Nine of the 28 species taken from this site showed changed levels of occurrence across time periods, but none of these conclusively showed a progressive decline with time (Table 10). One species showing a decline was *Oxyeleotris lineolatus*, but *O. herwerdini* increased in occurrence, probably indicating confusion in identifications.

4.2.3 Lake Daviumbu (DAV01) (April 1987 – February 2002)

Regression of species richness, abundance and biomass against time for catches from Lake Daviumbu detected a significant decline in species richness ($p = 0.038$; 26% reduction) and biomass ($p = 0.044$; 64% reduction), but no significant changes in abundance (Appendix 1i).

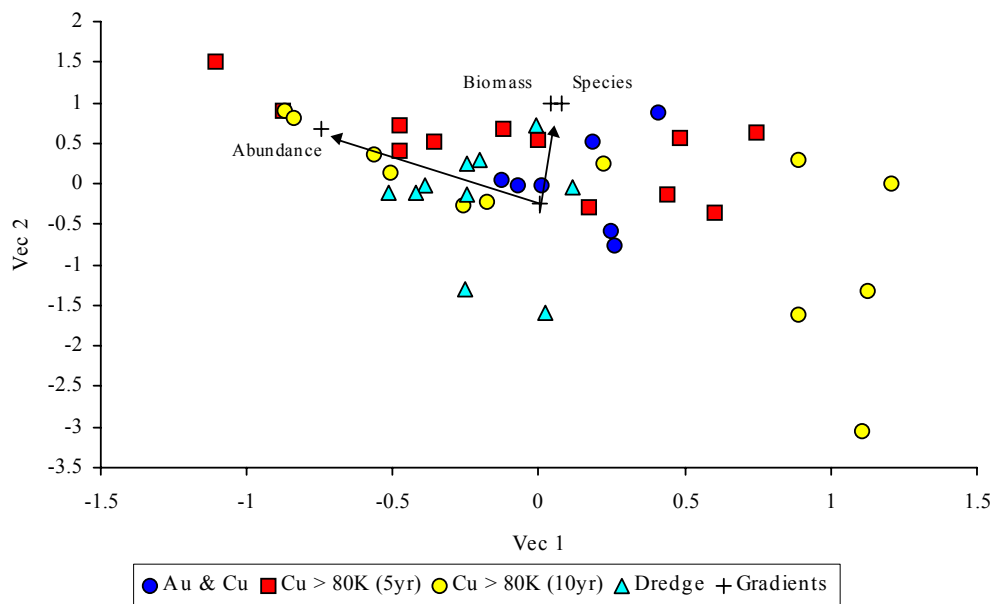


Figure 10 MDS ordination of Lake Daviumbu (DAV01) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with two dimensions and a stress of 0.1415).

Ordination of samples from Lake Daviumbu showed no clear separation of samples according to time periods (ANOSIM > 0.05), with considerable overlap in samples from successive time periods (Figure 10). There was no significant gradient in time ($p > 0.05$) indicating no systematic temporal changes. Gradients in species diversity, biomass and abundance through ordination space were all significant ($p < 0.01$), but did not reflect declines over time, but rather separation of groupings of sites with high abundance, species richness and biomass from sites with low values (Figure 10). Ten of the 43 species taken from this site showed significant changes in levels of

occurrence across time periods, but none of these conclusively showed a progressive decline with time (Table 11). As with other locations, *Oxyeleotris lineolatus* demonstrated a decline however, *O. herwerdini* increased in occurrence, probably indicating confusion in identifications.

Table 11. Species constancy in each time period for Lake Daviumbu (DAV01), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, p<0.05, ** p<0.01, *** p<0.001). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		2	3	4	5	Chi-square
Number of samples in each time period		7	12	12	10	significance
sp-10	Megalops cyprinoides	100	58	50	50	ns
sp-18	Nematalosa spp	100	100	83	100	ns
sp-20	Thryssa scratchleyi	86	33	0	60	**
sp-21	Thryssa rastroza	0	25	0	0	*
sp-25	Scleropages jardini	86	58	58	40	ns
sp-30	Arius leptaspis	100	100	100	80	ns
sp-32	Arius carinatus	0	0	0	20	ns
sp-34	Arius berneyi	100	100	50	70	**
sp-38	Cinetodus froggatti	43	0	0	40	**
sp-50	Neosilurus ater	100	100	92	90	ns
sp-52	Neosilurus sp.C	0	8	0	0	ns
sp-55	Neosilurus brevidorsalis	0	8	0	0	ns
sp-56	Porochilus obbesi	29	83	58	40	ns
sp-57	Porochilus meraukensis	0	0	17	0	ns
sp-58	Plotosus papuensis	14	0	0	0	ns
sp-59	Porochilus sp.	0	0	17	0	ns
sp-66	Liza alata (diadema)	29	50	0	30	*
sp-70	Melanotaenia splendida	0	17	33	50	ns
sp-86	Strongylura krefftii	100	92	75	100	ns
sp-95	Ambassis agrammus	14	25	25	40	ns
sp-97	Denarius bandata	0	8	0	0	ns
sp-98	Parambassis gulliveri	0	25	0	10	ns
sp-100	Lates calcarifer	57	42	8	40	ns
sp-105	Datnioides quadrifasciatus	0	17	0	0	ns
sp-113	Pingala lorentzi	29	8	8	0	ns
sp-114	Amniataba percoides	71	92	33	60	*
sp-115	Glossamia aprion	86	75	75	60	ns
sp-116	Glossamia trifasciata	14	8	0	10	ns
sp-120	Lutjanus argentimaculatus	0	8	0	0	ns
sp-121	Lutjanus goldiei	0	8	0	0	ns
sp-125	Acanthopagrus berda	14	25	0	0	ns
sp-135	Toxotes chatareus	57	67	17	80	*
sp-136	Toxotes lorentzi	0	17	0	0	ns
sp-146	Oxyeleotris fimbriata	43	92	8	0	***
sp-148	Oxyeleotris lineolatus	71	67	0	0	***
sp-161	Anabas testudineus	43	92	50	70	ns
sp-162	Clarias batrachus	0	0	0	10	ns
sp-163	Ophieleotris aporos	14	0	0	0	ns
sp-170	Oxyeleotris herwerdini	0	8	50	40	*
sp-186	Terapon lacustris	86	58	83	60	ns
sp-187	Terapon jarbua	0	8	0	0	ns
sp-189	Ambassis macleayi	0	0	8	20	ns
sp-190	Ambassis sp.	0	17	0	0	ns

4.2.4 Oxbow at Sembe (OXB03) (October 1989 – October 1998)

Linear regression of species richness, abundance and biomass against time for Sembe Oxbow detected a significant increase in abundance ($p = 0.0173$; 238% increase), but no significant changes in species richness or biomass over time (Appendix 1j).

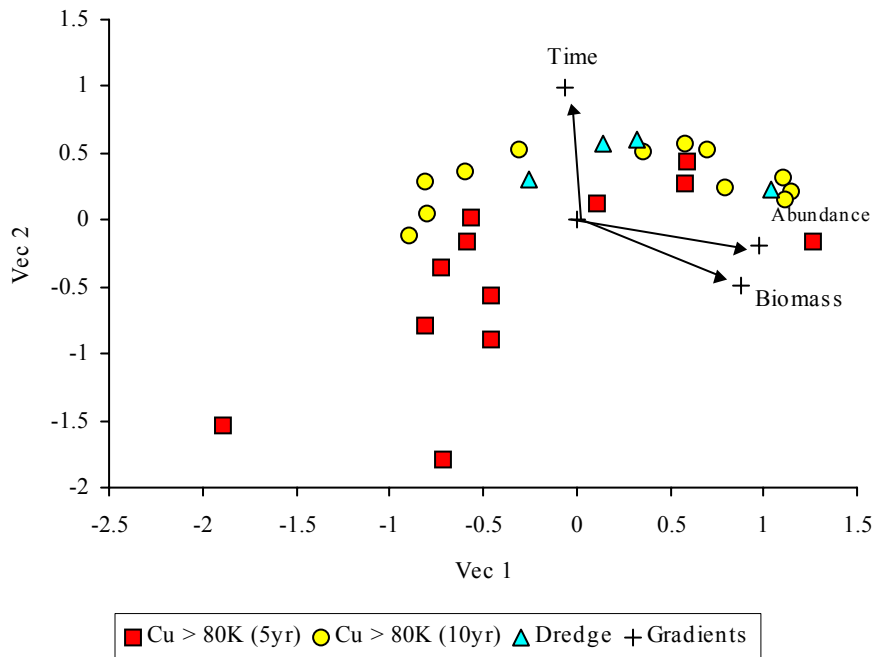


Figure 11 MDS ordination of Sembe Oxbow (OXB03) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with two dimensions and a stress of 0.1045).

Ordination of samples from Sembe Oxbow showed no clear separation of samples according to time periods (ANOSIM > 0.05), with considerable overlap in samples from successive time periods (Figure 11). There was a significant gradient in time ($p < 0.01$) through the ordination indicating a systematic change with time. As may be seen in the ordination (Figure 11), the earliest samples (Cu > 80K (5 yrs) tended to separate from samples collected in later time periods. Gradients in biomass and abundance through ordination space were significant ($p < 0.01$), although richness was not significant. Nine of the 36 species taken from this site showed significant changes in levels of occurrence across time periods, of which six showed progressive declines in occurrence with time; *Thryssa rastrosa*, *Liza alata (diadema)*, *Lates calcarifer*, *Datnioides quadrifasciatus*, *Toxotes chatareus*, *Oxyeleotris fimbriata* (Table 12). *Oxyeleotris fimbriata* demonstrated a decline however, *O. herwerdini* increased in occurrence, which may indicate mis-identifications. The declines in *Thryssa rastrosa* compares with significant declines in this species at riverine sites up and downstream of Sembe Oxbow (*viz.* Kaumbit, and Fly at Bosset and Obo). The reduction in occurrence of migratory species such as *Liza alata (diadema)*, *Lates calcarifer* and *Datnioides quadrifasciatus* may reflect loss of river channel – floodplain connectivity as a result of tie-channel blockage.

Table 12. Species constancy in each time period for Oxbow at Sembe (OXB03), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		3	4	5	Chi-square
Number of samples in each time period		12	12	4	significance
sp-10	Megalops cyprinoides	100	100	100	ns
sp-18	Nematalosa spp	100	100	100	ns
sp-20	Thryssa scratchleyi	42	25	100	*
sp-21	Thryssa rastrosa	67	83	0	*
sp-22	Thryssa spp	8	17	0	ns
sp-25	Scleropages jardini	92	100	100	ns
sp-30	Arius leptaspis	92	100	100	ns
sp-34	Arius berneyi	100	100	100	ns
sp-39	Nedystoma dayi	8	8	0	ns
sp-50	Neosilurus ater	100	83	100	ns
sp-55	Neosilurus brevidorsalis	8	0	0	ns
sp-56	Porochilus obbesi	50	25	50	ns
sp-57	Porochilus meraukensis	8	42	0	ns
sp-59	Porochilus sp.	0	8	0	ns
sp-60	Craterocephalus randi	0	17	0	ns
sp-66	Liza alata (diadema)	92	42	0	**
sp-69	Melanotaenia maccullochi	8	0	0	ns
sp-70	Melanotaenia splendida	33	33	0	ns
sp-86	Strongylura krefftii	100	100	100	ns
sp-95	Ambassis agrammus	8	33	25	ns
sp-98	Parambassis gulliveri	8	0	0	ns
sp-100	Lates calcarifer	100	33	25	**
sp-105	Datnioides quadrifasciatus	33	0	0	*
sp-114	Amniataba percoides	75	50	25	ns
sp-115	Glossamia aprion	0	8	0	ns
sp-121	Lutjanus goldiei	58	33	25	ns
sp-135	Toxotes chatareus	100	100	75	*
sp-136	Toxotes lorentzi	25	0	0	ns
sp-146	Oxyeleotris fimbriata	67	0	0	***
sp-148	Oxyeleotris lineolatus	33	8	0	ns
sp-150	Kurtus gulliveri	58	33	25	ns
sp-161	Anabas testudineus	42	42	50	ns
sp-162	Clarias batrachus	0	8	0	ns
sp-170	Oxyeleotris herwerdini	0	67	50	**
sp-186	Terapon lacustris	42	92	75	*
sp-189	Ambassis macleayi	0	25	25	ns

4.2.5 Lake Pangua (OXB05) (June 1989 – February 2002)

Regression of species richness, abundance and biomass against time in Lake Pangua detected a significant decline in species richness ($p = 0.0157$; 25% reduction), abundance ($p = 0.022$; 73% reduction) and biomass ($p = 0.0102$; 66% reduction (Appendix 1k).

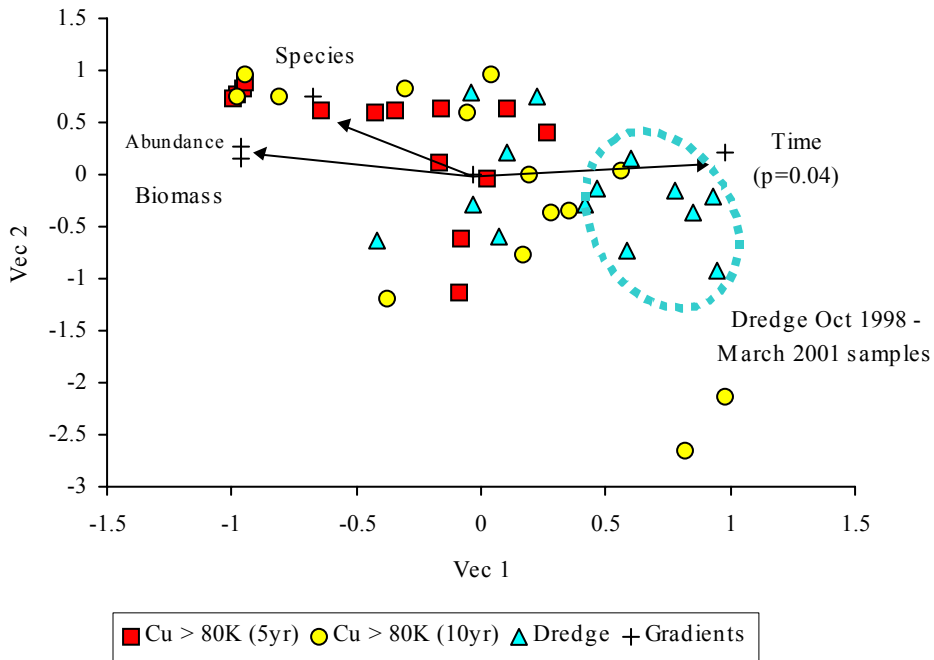


Figure 12 MDS ordination of Lake Pangua (OXB05) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with two dimensions and a stress of 0.1265).

Ordination of samples from Lake Pangua showed a significant separation of samples grouped by time periods (ANOSIM < 0.0001) (Figure 12). There was also a significant gradient in time ($p < 0.03$) through the ordination indicating a systematic change with time, whereby recent samples from the Dredge period tended to separate from earlier time periods, with the significant time gradient in the direction of the Dredge grouping. Gradients in species richness, biomass and abundance were all significant ($p < 0.01$), and in the opposite direction to the time gradient indicating a reduction in these parameters with time. Twelve of the 41 species taken from this site showed significant changes in levels of occurrence across time periods, of which eight showed progressive declines in occurrence – with time; *Megalops cyprinoides*, *Thryssa rastrosa*, *Porochilus obbesi*, *Liza alata (diadema)*, *Lutjanus goldiei*, *Toxotes lorentzi*, *Oxyeleotris fimbriata* and *Oxyeleotris lineolatus* (Table 13). *Oxyeleotris fimbriata* and *O. lineolatus* demonstrated a decline however, *O. herwerdini* increased in occurrence, which may indicate mis-identifications. As in Sembe Oxbow, *Thryssa rastrosa* had significant declines, and this species also declined at riverine sites up and downstream of Lake Pangua (*viz.* Kaumbit, and Fly at Bosset and Obo). The reduction in occurrence of migratory species such as *Liza alata (diadema)* and *Lutjanus goldiei* may reflect loss of river channel – floodplain connectivity as a result of tie-channel blockage.

Table 13. Species constancy in each time period for Lake Pangua (OXB05), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		3	4	5	Chi-square
Number of samples in each time period		14	14	14	significance
sp-10	Megalops cyprinoides	100	86	64	*
sp-18	Nematalosa spp	100	93	100	ns
sp-20	Thryssa scratchleyi	71	57	50	ns
sp-21	Thryssa rastrosa	43	21	0	*
sp-25	Scleropages jardini	100	93	79	ns
sp-30	Arius leptaspis	100	93	100	ns
sp-33	Arius augustus	7	0	0	ns
sp-34	Arius berneyi	100	100	100	ns
sp-38	Cinetodus froggatti	14	0	0	ns
sp-40	Cochlefelis spatula	14	0	0	ns
sp-41	Cochlefelis danielsi	7	0	0	ns
sp-50	Neosilurus ater	93	100	100	ns
sp-53	Neosilurus brevadorsalis	7	0	0	ns
sp-56	Porochilus obbesi	29	43	0	*
sp-57	Porochilus meraukensis	0	14	0	ns
sp-60	Craterocephalus randi	0	0	7	ns
sp-66	Liza alata (diadema)	93	36	43	*
sp-70	Melanotaenia splendida	7	21	29	ns
sp-86	Strongylura krefftii	100	86	100	ns
sp-90	Zenarchopterus novaeguinae	0	7	0	ns
sp-95	Ambassis agrammus	21	7	43	ns
sp-98	Parambassis gulliveri	14	7	29	ns
sp-100	Lates calcarifer	93	50	93	**
sp-105	Datnioides quadrifasciatus	36	7	21	ns
sp-113	Pingalla lorentzi	7	7	0	ns
sp-114	Amniataba percooides	100	36	71	**
sp-115	Glossamia aprion	21	21	43	ns
sp-121	Lutjanus goldiei	86	14	14	***
sp-125	Acanthopagrus berda	36	0	7	*
sp-130	Nibea semifasciatus	7	0	0	ns
sp-135	Toxotes chatareus	93	71	93	ns
sp-136	Toxotes lorentzi	36	0	0	**
sp-138	Scatophagus argus	7	0	14	ns
sp-139	Stenogobius lachneri	0	7	0	ns
sp-146	Oxyeleotris fimbriata	43	7	0	**
sp-148	Oxyeleotris lineolatus	43	0	0	***
sp-161	Anabas testudineus	64	50	64	ns
sp-162	Clarias batrachus	0	14	14	ns
sp-170	Oxyeleotris herwerdini	7	79	43	***
sp-186	Terapon lacustris	79	64	86	ns
sp-189	Ambassis macleayi	7	0	7	ns

4.2.6 Oxbow at ARM345 (OXB06) (June 1993 – March 2002)

Regression of species richness, abundance and biomass against time detected significant declines in species richness ($p = 0.0082$; 25% reduction), abundance ($p = 0.0006$; 82% reduction) and biomass ($p = 0.0103$; 52% reduction) in Oxbow at ARM345 (Appendix 11).

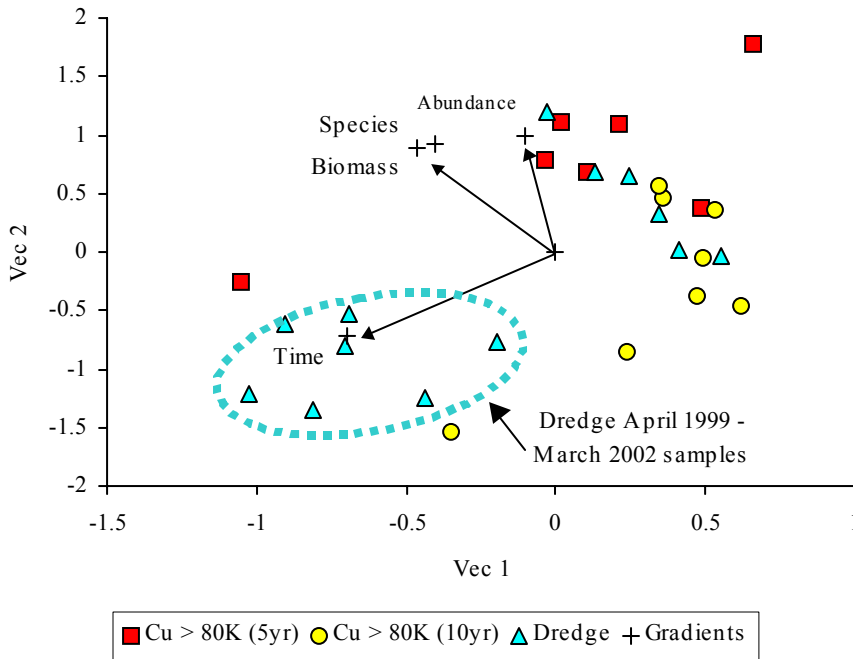


Figure 13 MDS ordination of Oxbow at ARM345 (OXB06) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with two dimensions and a stress of 0.0999).

Ordination of samples from Oxbow at ARM345 showed a trend for separation of samples by time periods, although the separation was not significant (ANOSIM = 0.09) (Figure 13). There was a significant gradient of time ($p < 0.01$) through the ordination indicating a systematic change with time. This was evident by a strong grouping of all recent samples collected in the Dredge period (April 1999 – March 2002) separating from the majority of samples in earlier time periods and from other samples in the Dredge period, with the significant time gradient in the direction of the subset of recent Dredge samples. This indicates a recent, but consistent change in fish assemblages in the Oxbow at ARM345. Gradients in species richness, biomass and abundance were all significant ($p < 0.01$), and were perpendicular to the time gradient indicating a weak reduction in these parameters with time. Eight of the 35 species taken from this site showed significant changes in levels of occurrence across time periods, of which six showed progressive declines in occurrence with time; *Thryssa rastrosa*, *Porochilus obbesi*, *Porochilus meraukensis*, *Datnioides quadrifasciatus*, *Kurtus gulliveri* and *Ambassis macleayi* (Table 14). As in Sembe Oxbow and Lake Daviumbu, and in riverine sites up and downstream of Oxbow ARM345 (*viz.* Kaumbit, and Fly at Bosset and Obo), *Thryssa rastrosa* had significant declines. The reduction in occurrence of migratory species such as *Datnioides quadrifasciatus* and *Kurtus gulliveri* may reflect loss of river channel – floodplain connectivity as a result of tie-channel blockage. Barramundi (*Lates calcarifer*) showed a trend of declining occurrence over time at this site, but changes were not significant. If this trend continues, it is likely only a matter of time until there is a significant decline in the occurrence of this species (Table 14). Similar trends exist for *Liza alata (diadema)* and *Lutjanus species*.

Table 14. Species constancy in each time period for Oxbow at ARM345 (OXB06), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		3	4	5	Chi-square
Number of samples in each time period		7	8	13	significance
sp-10	Megalops cyprinoides	100	100	92	ns
sp-18	Nematalosa spp	100	100	100	ns
sp-20	Thryssa scratchleyi	43	50	62	ns
sp-21	Thryssa rastrosa	71	63	0	**
sp-22	Thryssa spp	0	13	0	ns
sp-25	Scleropages jardini	100	100	100	ns
sp-30	Arius leptaspis	100	88	100	ns
sp-34	Arius berneyi	100	100	100	ns
sp-50	Neosilurus ater	100	63	100	*
sp-56	Porochilus obbesi	57	0	23	*
sp-57	Porochilus meraukensis	29	63	8	*
sp-58	Plotosus papuensis	0	13	0	ns
sp-59	Porochilus spp	0	13	0	ns
sp-66	Liza alata (diadema)	43	38	23	ns
sp-70	Melanotaenia splendida	29	0	38	ns
sp-86	Strongylura krefftii	100	100	85	ns
sp-95	Ambassis agrammus	29	13	15	ns
sp-98	Parambassis gulliveri	0	0	23	ns
sp-100	Lates calcarifer	71	88	46	ns
sp-105	Datnioides quadrifasciatus	57	13	8	*
sp-113	Pingalla lorentzi	29	0	8	ns
sp-114	Amniataba percoides	100	38	54	*
sp-115	Glossamia aprion	43	38	38	ns
sp-120	Lutjanus argentimaculatus	14	0	0	ns
sp-121	Lutjanus goldiei	29	50	15	ns
sp-130	Nibea semifasciatus	0	0	8	ns
sp-135	Toxotes chatareus	100	100	100	ns
sp-146	Oxyeleotris fimbriata	14	0	0	ns
sp-148	Oxyeleotris lineolatus	14	13	0	ns
sp-150	Kurtus gulliveri	29	0	0	*
sp-161	Anabas testudineus	57	50	31	ns
sp-170	Oxyeleotris herwerdini	57	63	69	ns
sp-186	Terapon lacustris	86	63	69	ns
sp-189	Ambassis macleayi	29	0	0	*
sp-190	Ambassis spp	14	0	0	ns

4.2.7 Strickland Oxbow (OXB08) (March 1992 – February 2002)

Regression of species richness, abundance and biomass against time for Strickland Oxbow did not detect any significant changes over time (Appendix 1m).

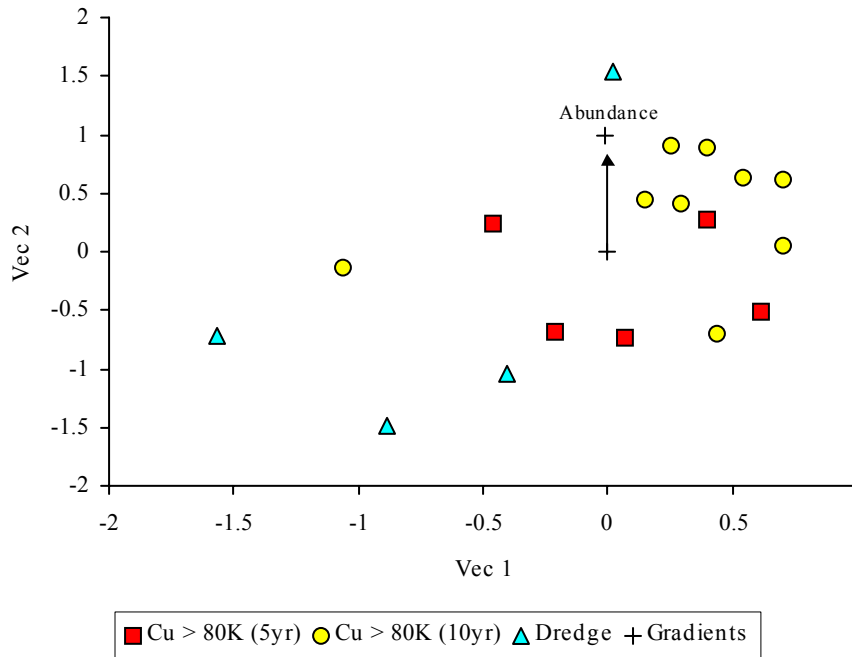


Figure 14 MDS ordination of Strickland Oxbow (OXB08) catch data, indicating significant gradients in community descriptors and time. The Time Period in which each sample was collected is indicated (optimum solution was attained with two dimensions and a stress of 0.1321).

Ordination of samples from Strickland Oxbow showed a significant separation of time periods in ordination space (ANOSIM = <0.0001) (Figure 14), however, the time gradient was not significant ($p > 0.05$) indicating there was no systematic change with time. Gradients in species richness and biomass through ordination space were not significant, with the only significant gradient being for abundance ($p < 0.01$). These results all suggest not strong changes in assemblages at this location over time. At the species level, four of the 47 species taken from this site showed significant changes in levels of occurrence across time periods, of which three showed progressive declines in occurrence with time; *Arius carinatus*, *Cinetodus crassilabris* and *Lutjanus argentimaculatus*. (Table 15). The declines in these species may be real, or could reflect mis-identifications with similar species, particularly for *Lutjanus argentimaculatus* versus *L. goldiei*. The freshwater sawfish, *Pristis microdon*, which has been lost from middle Fly riverine and floodplain sites, is exhibiting declines in occurrence at Strickland oxbow. This may be a system-wide reduction in this species, or effects of fishing pressure at this site.

Table 15. Species constancy in each time period for Strickland Oxbow (OXB08), giving percentage of samples in each time period in which each species was present and significance of chi-squared test (ns, not significant, *, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Time period contributing most to the chi-sq statistic is highlighted in bold.

Time period		3	4	5	Chi-square
Number of samples in each time period		5	9	4	significance
sp-1	Pristis microdon	60	78	75	ns
sp-10	Megalops cyprinoides	100	67	50	ns
sp-18	Nematalosa spp	100	100	100	ns
sp-20	Thryssa scratchleyi	100	100	100	ns
sp-21	Thryssa rastroso	60	89	0	**
sp-22	Thryssa spp	20	11	0	ns
sp-25	Scleropages jardini	80	100	100	ns
sp-30	Arius leptaspis	100	67	75	ns
sp-32	Arius carinatus	20	0	0	ns
sp-33	Arius augustus	40	44	50	ns
sp-34	Arius berneyi	100	100	100	ns
sp-35	Cinetodus crassilabris	0	11	0	ns
sp-38	Cinetodus froggatti	80	78	25	ns
sp-39	Nedystoma dayi	20	89	75	*
sp-41	Cochlefelis danielsi	40	11	0	ns
sp-50	Neosilurus ater	60	67	75	ns
sp-56	Porochilus obbesi	40	67	25	ns
sp-57	Porochilus meraukensis	0	56	0	*
sp-58	Plotosus papuensis	40	0	0	ns
sp-66	Liza alata (diadema)	80	44	100	ns
sp-70	Melanotaenia splendida	0	22	0	ns
sp-86	Strongylura krefftii	80	100	100	ns
sp-95	Ambassis agrammus	40	22	0	ns
sp-98	Parabassiss gulliveri	60	100	100	ns
sp-100	Lates calcarifer	100	100	100	ns
sp-105	Datnioides quadrifasciatus	20	11	0	ns
sp-114	Amniataba percoides	60	78	75	ns
sp-115	Glossamia aprion	0	33	0	ns
sp-120	Lutjanus argentimaculatus	0	11	0	ns
sp-121	Lutjanus goldiei	60	89	50	ns
sp-125	Acanthopagrus berda	20	0	0	ns
sp-130	Nibea semifasciatus	20	33	50	ns
sp-135	Toxotes chatareus	100	100	100	ns
sp-146	Oxyeleotris fimbriata	20	11	0	ns
sp-148	Oxyeleotris lineolatus	40	11	0	ns
sp-150	Kurtus gulliveri	80	100	75	ns
sp-161	Anabas testudineus	20	33	25	ns
sp-170	Oxyeleotris herwerdini	40	67	100	ns
sp-186	Terapon lacustris	0	33	50	ns
sp-189	Ambassis macleayi	0	11	0	ns

4.3. Synthesis of Results

Results of changes in species assemblages with time and chi-square contingency table analysis of changes in the frequency of occurrence of each species at each site between time periods are summarised in Table 16 and Figure 15. These show that the greatest loss of species and declines in occurrence of species occurred at riverine sites closest to the mine (FLY10, FLY14 and FLY15). Site TED35 at New Atkamba was an exception, with fewer species in decline or lost. All these sites had significant time gradients through their ordinations, indicating a progressive change in assemblage structure over time. At all sites the gradient was in the opposite direction to gradients in community descriptors (species richness, abundance and biomass), indicating a decline in these parameters over time. Again, the exception was TED35 where community descriptors increased over time.

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Table 16. Summary of declines in species at each site (X = species previously common, but not recorded in last time period; ↓ = species still present but showing a significant decline (p<0.05) according to Chi-square test; → = a significant change between time periods, but with lowest occurrences in intermediate years, ns = no significant change in occurrence according to Chi Square test; “-“ = species never recorded from site).

Code	Species	TED35	FLY10	FLY14	FLY15	FLY20	STR01	BOS10	BOS11	DAV01	OXB03	OXB05	OXB06	OXB08
1	<i>Pristis microdon</i>	-	-	X	X	ns	ns	X	-	-	-	-	-	ns
10	<i>Megalops cyprinoides</i>	ns	ns	↓	↓	ns	ns	ns	ns	ns	ns	↓	ns	ns
15	<i>Clupeoides papuensis</i>	ns	ns	ns	ns	-	ns	-	-	-	-	-	-	-
18	<i>Nematalosa spp</i>	↑	→	ns	ns	ns	ns	→	→	ns	ns	ns	ns	ns
20	<i>Thryssa scratchleyi</i>	ns	→	ns	ns	ns	ns	↓	X	→	→	ns	ns	ns
21	<i>Thryssa rastrorsa</i>	ns	X	X	↓	X	ns	X	ns	X	X	X	X	X
22	<i>Thryssa spp</i>	-	-	-	-	ns	-	ns	ns	-	ns	-	ns	ns
25	<i>Scelopages jardini</i>	ns	↓	ns	ns	ns	ns	↓	ns	ns	ns	ns	ns	ns
30	<i>Arius leptaspis</i>	↑	ns	ns	ns	ns	→	ns	ns	ns	ns	ns	ns	ns
31	<i>Arius latirostris</i>	ns	↓	X	ns	X	ns	-	-	-	-	-	-	-
32	<i>Arius carinatus</i>	X	↓	↓	ns	↓	↓	-	-	ns	-	-	-	ns
33	<i>Arius augustus</i>	-	X	↓	X	↓	ns	ns	-	-	-	ns	-	ns
34	<i>Arius berneyi</i>	↑	ns	ns	ns	ns	ns	ns	→	→	ns	ns	ns	ns
35	<i>Cinetodus crassilabris</i>	ns	↓	X	X	↓	↓	-	-	-	-	-	-	ns
36	<i>Arius macrorhynchus</i>	↓	↓	↓	↓	→	ns	-	-	-	-	-	-	-
37	<i>Arius taylori</i>	→	ns	-	-	-	ns	-	-	-	-	-	-	-
38	<i>Cinetodus froggatti</i>	ns	↓	↓	X	ns	ns	X	-	→	-	ns	-	ns
39	<i>Nedystoma dayi</i>	-	↓	X	ns	ns	ns	-	-	-	ns	-	-	↑
40	<i>Cochlefelis spatula</i>	ns	↓	↓	ns	ns	ns	ns	-	-	-	ns	-	-
41	<i>Cochlefelis danielsi</i>	-	ns	ns	ns	ns	ns	-	-	-	-	ns	-	ns
50	<i>Neosilurus ater</i>	→	→	ns	ns	ns	ns	ns	ns	ns	ns	ns	→	ns
51	<i>Neosilurus equinus</i>	ns	ns	-	-	-	-	-	-	-	-	-	-	-
52	<i>Neosilurus sp.C</i>	-	ns	-	-	-	-	-	-	ns	-	-	-	-
53	<i>Neosilurus brevidorsalis</i>	-	-	-	-	-	-	ns	-	ns	ns	ns	-	-
55	<i>Oloplotosus luteus</i>	-	ns	ns	-	-	-	-	-	-	-	-	-	-
56	<i>Porochilus obbesi</i>	ns	↑↓	ns	ns	→	ns	ns	→	ns	ns	X	→	ns
57	<i>Porochilus meraukensis</i>	-	↓	X	-	-	ns	↑	→	ns	ns	ns	↓	X
58	<i>Plotosus papuensis</i>	↓	ns	ns	-	ns	-	ns	-	ns	-	-	ns	ns
59	<i>Porochilus spp</i>	-	-	ns	-	-	-	-	-	ns	ns	-	ns	-
60	<i>Craterocephalus randi</i>	ns	→	-	-	-	-	-	-	-	ns	ns	-	-
65	<i>Crenimugil labiosus</i>	-	ns	ns	-	-	-	-	-	-	-	-	-	-
66	<i>Liza alata (diadema)</i>	ns	↓	↓	↓	ns	ns	ns	-	→	X	↓	ns	ns
68	<i>Liza macrolepis</i>	-	-	-	-	ns	-	-	-	-	-	-	-	-
69	<i>Melanotaenia maccullochi</i>	-	-	-	-	-	-	-	-	-	ns	-	-	-
70	<i>Melanotaenia splendida</i>	ns	→	ns	→	ns	-	ns	ns	ns	ns	ns	ns	ns
86	<i>Strongylura krefftii</i>	ns	→	ns	→	ns	ns	→	→	ns	ns	ns	ns	ns
90	<i>Zenarchopterus novaeguinae</i>	ns	ns	-	-	ns	-	-	-	-	-	ns	-	-
95	<i>Ambassis agrammus</i>	ns	↑	ns	ns	X	ns	ns	ns	ns	ns	ns	ns	ns
97	<i>Denarius bandata</i>	-	-	-	-	-	-	ns	-	ns	-	-	-	-
98	<i>Parambassis gulliveri</i>	ns	↓	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
100	<i>Lates calcarifer</i>	ns	↓	ns	ns	ns	ns	↓	ns	ns	↓	→	ns	ns
105	<i>Datnioides quadrifasciatus</i>	ns	ns	ns	ns	ns	ns	ns	-	ns	X	ns	↓	ns

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Code	Species	TED35	FLY10	FLY14	FLY15	FLY20	STR01	BOS10	BOS11	DAV01	OXB03	OXB05	OXB06	OXB08
110	<i>Hephaestes roemeri</i>	X	ns	ns	ns	-	-	-	-	-	-	-	-	-
113	<i>Pingalla lorentzi</i>	ns	→	ns	-	ns	-	ns	ns	ns	-	ns	ns	-
114	<i>Amniatamba percoides</i>	ns	→	ns	ns	ns	ns	→	↓	→	ns	→	→	ns
115	<i>Glossamia aprion</i>	ns	→	ns	ns	ns	ns	→	ns	ns	ns	ns	ns	ns
116	<i>Glossamia trifasciata</i>	-	ns	-	-	-	-	-	-	ns	-	-	-	-
120	<i>Lutjanus argentimaculatus</i>	-	↓	ns	X	ns	X	ns	-	ns	-	-	ns	ns
121	<i>Lutjanus goldiei</i>	ns	↓	ns	ns	ns	ns	ns	-	ns	ns	↓	ns	ns
125	<i>Acanthopagrus berda</i>	-	↓	ns	ns	ns	ns	-	-	ns	-	↓	-	ns
130	<i>Nibea semifasciata</i>	ns	ns	↓	ns	ns	ns	-	-	-	-	ns	ns	ns
135	<i>Toxotes chatareus</i>	ns	→	ns	ns	ns	ns	ns	ns	→	↓	ns	ns	ns
136	<i>Toxotes lorentzi</i>	-	-	X	ns	ns	ns	X	ns	ns	ns	X	-	-
138	<i>Scatophagus argus</i>	-	-	ns	ns	ns	-	-	-	-	-	ns	-	-
139	<i>Stenogobius lachneri</i>	-	-	-	-	-	-	-	-	-	-	ns	-	-
140	<i>Glossogobius giurus</i>	ns	ns	-	-	-	-	-	-	-	-	-	-	-
142	<i>Glossogobius sp.</i>	-	ns	-	-	-	-	-	-	-	-	-	-	-
143	<i>Glossogobius concavifrons</i>	ns	-	-	-	-	-	-	-	-	-	-	-	-
145	<i>Mogurnda mogurnda</i>	-	ns	-	ns	-	-	-	-	-	-	-	-	-
146	<i>Oxyeleotris fimbriata</i>	-	ns	X	ns	ns	ns	X	X	X	X	X	ns	ns
147	<i>Oxyeleotris nullipora</i>	-	-	-	ns	ns	-	-	-	-	-	-	-	-
148	<i>Oxyeleotris lineolatus</i>	ns	ns	ns	ns	ns	ns	X	X	X	ns	X	ns	ns
150	<i>Kurtus gulliveri</i>	-	X	ns	-	ns	ns	ns	-	-	ns	-	X	ns
161	<i>Anabas testudineus</i>	ns	↑	↑	ns	ns	ns	↑	ns	ns	ns	ns	ns	ns
162	<i>Clarias batrachus</i>	ns	↑	↑	ns	ns	ns	ns	ns	ns	ns	ns	-	-
163	<i>Ophieleotris aporos</i>	-	-	-	-	ns	-	-	-	ns	-	-	-	-
164	<i>Tetranesodon conorhynchus</i>	-	-	-	-	ns	ns	-	-	-	-	-	-	-
167	<i>Arius sp.A</i>	-	-	-	-	-	ns	-	-	-	-	-	-	-
168	<i>Arius agreutes</i>	ns	-	-	-	ns	ns	-	-	-	-	-	-	-
170	<i>Oxyeleotris herwerdini</i>	ns	↑	↑	ns	ns	ns	↑	ns	↑	↑	↑	ns	ns
171	<i>Mogurnda cingulata</i>	-	ns	-	-	-	-	-	-	-	-	-	-	-
172	<i>Oxyeleotris spp</i>	-	-	ns	-	-	-	-	-	-	-	-	-	-
181	<i>Liza subviridis</i>	-	ns	ns	-	-	-	-	-	-	-	-	-	-
184	<i>Carcharhinus leucas</i>	-	-	-	-	ns	-	-	-	-	-	-	-	-
186	<i>Terapon lacustris</i>	ns	↑	ns	ns	ns	ns	ns	ns	ns	↑	ns	ns	ns
187	<i>Terapon jarbua</i>	-	-	-	-	-	-	-	-	ns	-	-	-	-
189	<i>Ambassis macleayi</i>	-	-	ns	-	-	-	ns	ns	-	-	ns	X	ns
190	<i>Ambassis spp</i>	-	ns	-	-	-	-	-	-	ns	-	-	ns	-
191	<i>Hephaestes fuliginosus</i>	-	ns	ns	-	-	-	-	-	-	-	-	-	-
No. species lost (X)		2	3	8	5	3	1	6	3	3	4	5	3	2
No. species in decline (↓)		2	15	8	4	3	2	3	1	0	2	4	2	0
No. species increasing (↑)		3	6	3	0	0	0	3	0	1	2	1	0	1
No species with sign variability (→)		2	10	0	2	2	1	4	5	6	1	2	3	0

Within the floodplain sites, the highest rates of loss and decline in species across time periods were at Lake Pangua (OXB05), Bosset Lagoon (BOS10), Sembe Oxbow (OXB03) and Oxbow at ARM345 (OXB06). Within these sites, there were significant gradients in time through the ordinations for Sembe Oxbow (OXB03), Lake Pangua (OXB05) and Oxbow at ARM345 (OXB06). Gradients in community descriptors also were significant (except for species richness at Sembe Oxbow), and generally opposed or perpendicular to the time gradient, indicating weak declines over time. It is likely that these gradients will become stronger over time if these trends continue.

From Table 16 it may be seen where there are consistent patterns of decline/loss of some species across sites. For example, *Thryssa scratchleyi* and particularly *Thryssa rastrorsa* consistently have declined or been lost from many sites. It is possible that the latter has not been recorded due to confusion in identifications with the former, however, both species have declined at several sites, suggesting these are real losses. Other species consistently showing declines are *Oxyeleotris fimbriata* and *Oxyeleotris lineolatus*, especially at floodplain sites. However, *Oxyeleotris herwerdini* has increased in occurrence at most sites at which the former species have declined, and this is almost certainly due to mis-identification of the former with the latter. Other species notable for their declines, especially at riverine sites are many of the forktailed catfishes; *Arius latirostris*, *Arius carinatus*, *Arius augustus*, *Cinetodus crassilabris*, *Arius macrorhynchus*, *Cinetodus froggatti*, *Nedystoma dayi*, *Cochlefelis spatula*. The mullet *Liza alata (diadema)* has also declined at the most impacted riverine sites, and also at those ORWB sites showing greatest declines (OXB05, OXB03 and BOS10). At floodplain sites there are several instances of species showing reduced frequency of occurrence in intermediate years, but with levels recovery again (i.e. *Arius berneyi*, *Porochilus obbesi*, *Porochilus meraukensis* and *Amniataba percoides*). This undoubtedly reflects declines in the populations of these species at floodplain sites in El Niño years, with following lags in recovery.

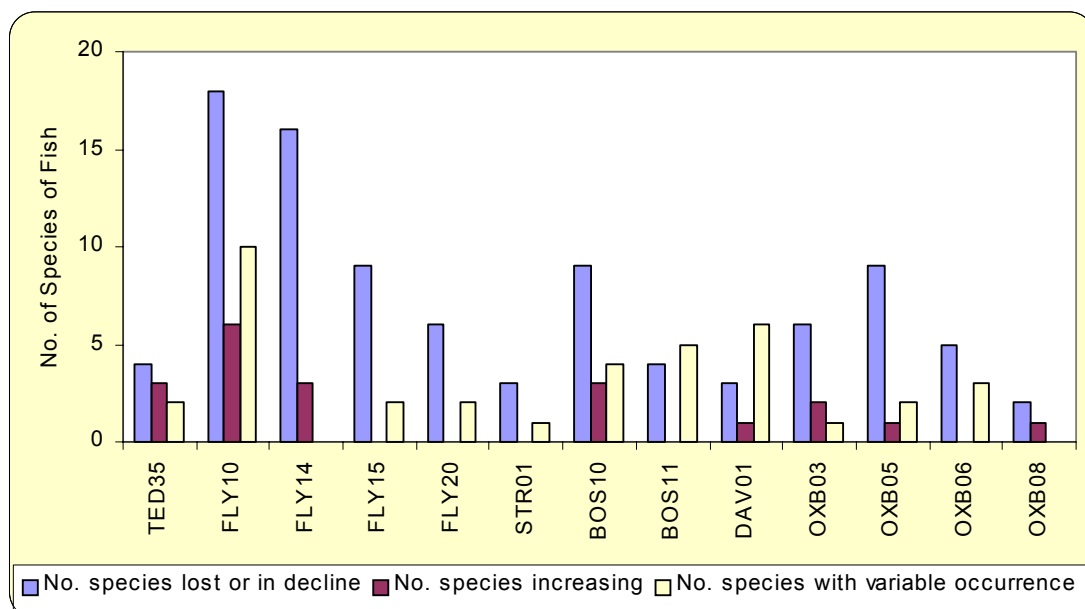


Figure 15. Changes in species occurrences at sites, as determined from chi-square analysis, showing for each site a.) the number of species either no longer recorded or significantly reduced in occurrence, b.) number of species with a significant increase in occurrence, and c.) number of species with a significant change in occurrence between time periods, but without a trend for increasing or decreasing occurrence (refer Table 16 for details).

5 Discussion

5.1 Previous Analyses

Multivariate analysis of changes in fish community structure for subsets of the OTML database (riverine & ORWB sites) have been applied at various times in the past. Smith & Morris (1992) ordinated fish catch data (abundance and biomass) from Ningerum, Atkamba and Kuambit, for the period 1983 to 1989 and recorded significant separation of groups of samples in ordination space related to mine operating periods. They also detected significant gradients in water quality parameters (suspended solids, dissolved and particulate copper) through ordination space, suggesting a relationship between changes in community structure and changes in water quality due to the mine. Multivariate analysis (ordination) was also performed on ORWB catch data collected upto 30th September 1992 (OTML, 1993), however, small sample size for some sites (i.e. Floodplain sites at Bosset and Obo, and Oxbows 1 & 2) restricted the possible analysis and interpretation. Nonetheless, the analysis did detect significant clustering of samples, but there were no significant relationships that could be attributed to mine operating periods. However, there were significant groupings of samples within data sets for Bosset Lagoon (BOS10) and Sembe (OXB03) which were thought to relate to El Niño droughts. Principal Axis Correlation (PCC) analysis conducted by OTML (1993) detected significant gradients in suspended solids, and particulate and dissolved copper concentrations through the ordinations of data from Lake Daviumbu (DAV01) and Bosset Lagoon (BOS10). The presence of these gradients could be interpreted as a mine-related influence on community structure in these ORWBs.

More recently, Storey (1997) undertook a detailed multivariate analysis of all riverine catch data to compare fish assemblages between sites for specific time periods, and also to assess changes in assemblage structure at each site over time; floodplain sites were not included in these analyses.

Analysis of spatial changes in community structure by Storey (1997) identified several consistent patterns across time periods. In the baseline data (1983/84) there were species that increased in abundance at upland sites (e.g. *Neosilurus. equinus* and *Crenimugil. labiosus*), however, these gradients no longer appeared in ordinations of later time periods, reflecting the loss of these species from the Ok Tedi after mining commenced. Analysis of baseline data also showed the clear separation of upper Ok Tedi and tributary sites from lower Ok Tedi and upper Fly River sites. This demonstrated the inherent difference in community structure between the faster flowing, shallower reaches and the deeper, slower-flowing lowland reaches.

In later time periods, there was reduced differentiation between middle Fly River sites (FLY10 and FLY14) and upper Fly (FLY02) and lower Ok Tedi (TED30/35) sites, indicating that community structure at Middle Fly River sites was changing to become more similar to that found in the lower Ok Tedi and at Kuambit, possibly in response to mine effects. Also, with each subsequent time period, Storey (1997) reported increased variability within each grouping of sites close to the mine, indicated increasing variability in the composition of catches between sampling occasions.

However, lower Fly and Strickland River sites tended to maintain low variability (i.e. catches were more predictable).

Storey (1997) also reported a consistent pattern of gradual changes in community structure at sites over time. These changes were greatest at sites closest to the mine (TED30 & FLY10), with less differentiation (i.e. less separation/reduced change in community structure; viz. less impact) between time periods with increasing distance from the mine. For sites furthest from the mine (e.g. sites at Bosset, Obo, and Ogwa), only the most recent time periods appeared to be separating, suggesting that changes in community structure at these sites were only becoming evident at that time (1996/97). This was supported by the relatively recent (1993 onwards) reporting of significant declines in fish catches at sites further from the mine (OTML, 1994, 1995). In most instances, the spatial separation of time periods in ordination space were supported by significant negative gradients in biomass, abundance and species richness, indicating that these parameters were decreasing with time. The negative gradients were strongest at sites closest to the mine (Ok Tedi and Kuambit), and were supported by a directly opposing gradient of time (i.e. as time increased, species richness decreased).

Additional analysis showed changing frequencies of occurrence of species at sites over time. There were a few species that showed an increase in occurrence with time (e.g. the introduced *Anabas testudineus*, which was first recorded from the river system in 1987 and was becoming more common), and some that appeared to change in occurrence in the intermediate time periods (e.g. *Nematalosa* spp at FLY10 which had lower abundances in the mid- 1980s compared to the early 1980s and 1990s). However, the majority of species with significant changes had declined in occurrence in the most recent time period(s). In many instances there were species which had not been recorded in the last one or two time periods (i.e 3 – 6 years). This was particularly evident at sites closest to the mine (Atkamba and Kuambit), with the incidence of “lost” species declining with distance from the mine. These results were of particular concern, since they suggested the loss of species from the system or parts of the system, with implications for the maintenance of a subsistence fishery reliant upon these species, and also for ecosystem recovery following mine closure.

Based on the results of analyses performed by Storey (1997), it was recommended that multivariate analysis should be periodically repeated (every 3 years) to assess the extent of continued changes in community structure at key monitoring sites, and Chi-square Contingency Table Analysis should also be repeated to monitor changing occurrence of species, particularly to identify continued/further losses of species from key sites.

The current analyses were performed in response to these recommendations, to assess the extent of continued changes in fish assemblages at each site over time, to monitor changes in the occurrence of species at each site over time, and particularly to assess the loss of species from parts of the system, or from the system as a whole. The analyses were expanded to included floodplain sites, because these data had not been analysed using these methods since the early 1990s, and there was a potential for declining catches at some ORWB sites as a result of mine-related effects (i.e. forest die-back, tie channel blockage and potential water quality issues related to intrusion of mine derived sediments into floodplain waterbodies). Analyses were also supported

with linear regression analyses of changes in species richness, abundance and biomass against time, as these analyses had not been performed for several years, and would assist in identifying temporal changes in catches at each site.

5.2 Temporal changes in community structure

Re-analysis of temporal changes were performed for all riverine and floodplain sites, with the exception of TED20 and TED30, because no additional data had been collected from these sites since the analyses by Storey (1997), and therefore the analyses, results and conclusions have not changed.

Analyses of riverine sites showed the same consistent pattern of changes in community structure with time at each site as reported by Storey (1997). Observed changes were greatest at sites closest to the mine (i.e. Kuambit), but with strong effects also detectable at Bosset and Obo. These changes in species assemblages were supported by the significant declines in species richness, abundance and biomass at these sites. In most instances, the spatial separation of time periods in ordination space was supported by significant gradients in community descriptors, indicating that species richness, abundance and biomass were decreasing with time. These gradients were strongest at sites closest to the mine (Kuambit, Bosset and Obo), and were supported by a directly opposing gradient in time.

The significant gradients of decreasing species richness through the ordinations were supported by the results of Chi-square Contingency Table analyses. This technique compares the frequency of occurrence of each species in each time period, and statistically determines if the frequency is greater or less than expected for the number of samples in the period. These analyses identified species at most sites which showed changing frequencies of occurrence across time periods. The majority of species with significant Chi-square statistics had changed in occurrence in the most recent time period(s), and the majority of these species had declined in occurrence, with some species no longer recorded from some sites. Of particular concern were a suite of forktailed catfish at Kuambit, Bosset and Obo. Species losses were most evident at sites closest to the mine (Kuambit, Bosset and Obo), with the incidence of "lost" species, and of significant changes in frequency declining with distance from the mine. The chi-square approach complements analyses using ordination plots, whereby the loss of a species at a site will result in separation of samples in ordination space. However, chi-square analysis will not always support the multivariate analyses, because, for a chi-square test to be significant it relies on a species becoming rarer at, or disappearing from a site, whereas, the ordinations can differentiate sites on a reduction in the abundance of a species or a suite of species relative to earlier data, even though all species still occur at the site.

The exception to the above trend of declining assemblages at riverine sites was at New Atkamba (TED35) where there appeared to be increasing community descriptors with time, with increasing frequency of occurrence of some fish species. This may reflect the benefits of the dredge operation at this site. Alternatively, it could reflect the return of some species in response to reduced flows (and sediment loads) during the El Niño droughts.

Results for riverine sites generally support earlier results by Storey (1997), although they do indicate worsening conditions at riverine sites further downstream of the mine (FLY14 and FLY15). It has frequently been acknowledged that there has been a loss of species from the main channel of the Ok Tedi (Wood *et al*, 1994). However, it has always been argued that these species either are still present in tributaries or are present in the main river and therefore, the system retains its capacity to return to pre-mine composition. These analyses indicate that some of these species are becoming even more restricted in their distribution, especially the suite of forktailed catfish disappearing from riverine sites. If the trend continues, some species may be lost from the entire middle Fly River as well as the Ok Tedi, which would seriously restrict the systems capacity to recover. A broader biodiversity study is required to establish the continued presence of these species at sites not routinely monitored by OTML.

For some species there may be explanations for changes in occurrence that are not mine-related. For instance, the Saw Fish, *Pristis microdon*, which Allen (1991) records as being common in the middle Fly River, has not been recorded from upstream of Everill Junction in the last ~ 10 years. However, this species is still commonly caught in gill nets downstream of Everill Junction, and in the Strickland River. Because of its morphology (i.e. elongate snout lined with two rows of laterally projecting teeth), this species is easily caught by gill nets, and it could be that it has been 'fished-out' of the middle Fly system by the increased incidence of gill netting. Further evidence for this is declining occurrence of freshwater sawfish at Strickland oxbow (OXB08), possibly reflecting fishing pressure by OTML sampling. However, it is equally plausible that this species is susceptible to mine impacts and avoids the Fly River upstream of the major point of dilution at Everill Junction.

However, for other riverine species there is no obvious reason for the observed declines, apart from mine-related effects, particularly the loss of fish habitat as reported by Storey & Marshall (2003).

The series of El Niño droughts that have affected the Fly River over the last twenty years also could be responsible for some patterns in the data, with fish moving into the river, from the drying floodplain, causing a change in community structure; community composition in the river is distinct from that on the floodplain. This would be particularly evident in the most recent time periods, during which there have been a series of successive droughts. This could explain the separation of the most recent time period from successive periods in analysis of data for some sites (e.g. Ogwa and Strickland River).

Results from analysis of floodplain sites indicate effects at ORWB sites not previously observed. Earlier analyses of floodplain sites have shown declines in catch rates in 'intermediate' years, but with subsequent recovery in catches in recent years. These changes had not been attributed to mine effects, but to stress/drying due to El Niño droughts (i.e. DAV01 and BOS10/BOS11) and to algal blooms (OXB05). However, a series of sites (BOS10, DAV01, OXB03, OXB05 and OXB06) are now showing trends of progressive declines in catch (ref Appendices) and changes in assemblage composition, which are not readily explicable by natural events. For example, OXB05 and OXB06 show a distinct grouping of recently collected samples in ordination space, with these samples separating from earlier samples. There are also declines in species richness, abundance and biomass at floodplain sites over time,

and even allowing for effects of droughts and algal blooms, these declines would still be significant. Some of the changes in fish assemblages at floodplain sites likely relate to mis-identification of species, however, changes in other species are not so readily explicable.

It is generally agreed that parts of the floodplain of the middle Fly River (between D'Albertis Junction and Everill Junction) is being affected by forest die-back, and ORWBs are affected by deposition of mine derived sediments and tie-channel blockage. Based on these potential mine-related pressures, and the observed effects on fish assemblages, it can only be concluded that mine effects are now progressing onto the floodplain. Previously, significant mine effects have been restricted to riverine sites, and have not been detected at floodplain sites. Declines in floodplain fish catch has potential implications for the maintenance of a subsistence fishery on the floodplain. Impacts at riverine sites initially appeared in the late 1980s and early 1990s as 'non-significant' trends of declining catch, but these trends then became progressively stronger and finally became significant as mine impacts grew greater. The concern is that effects being detected at floodplain sites are comparable to the early trends observed at riverine sites in the late 1980s/early 1990s, and these effects at floodplain sites will progressively become greater with time.

The mechanisms and processes by which the mine may be affecting floodplain fish assemblages are unknown, but may be inferred. Possible mechanisms are:

- changes in food web structure due to forest die-back around forested floodplain sites,
- loss of floodplain connectivity with the main channel due to tie-channel blockage restricting access to migratory species , and,
- chronic toxicity effects due to release of metals from mine-derived sediments deposited onto the floodplain.

A review of the life history traits of those fish species demonstrating declines over recent years should be conducted to assess any commonality in traits, particularly if there are traits which could make the species more susceptible to mining effects. Factors to look at should include major life-history features such as feeding-group, migratory/non-migratory behaviour, habitat requirements, normal spatial distribution (i.e. riverine or floodplain species), and spawning mode. The potential risks to fish assemblages of floodplain sites from tie-channel blockage, disruption to food webs from forest die-back and chronic toxicity effects from release of metals under stratification need to be assessed.

6 Recommendations

- The potential risks to fish assemblages of floodplain sites from tie-channel blockage, disruption to food webs from forest die-back and chronic toxicity effects from release of metals from mine-derived sediments deposited on the floodplain need to be assessed.
- The biodiversity study should be used to assess the broader occurrence of species that appear to be in decline at riverine and floodplain sites
- The potential for mid-identification of some species to be affecting analyses should be investigated. Particularly looking at the *Thryssa* and *Oxyeleotris* species complexes.
- Life history traits of those fish species demonstrating declines over recent years should be reviewed to assess any commonality in traits, particularly if there are traits which could make the species more susceptible to mining effects. Factors to be examined should include major life-history features such as feeding-group, migratory/non-migratory behaviour, habitat requirements, normal spatial distribution (i.e. riverine or floodplain species), and spawning mode.
- Gradients in water quality parameters (e.g. TSS, pCu and dCu concentrations) should be incorporated in the above analyses to complement the use of time in days from commencement of mining as a variable. This will require compilation of available data for equivalent sites from the OTML databases. Grouping of sampling periods into El Niño/La Niña events also should be incorporated to assess effects fo these climatic events.
- Multivariate analysis has proven useful in detecting spatial and temporal changes in community structure at riverine and floodplain sites. These analyses should be periodically repeated (every 3 years) to assess the extent of continued changes in community structure at key monitoring sites.
- Chi-square Contingency Table Analysis should also be regularly repeated to monitor changing occurrence of species. It is imperative that continued/further losses of species from key sites is identified.

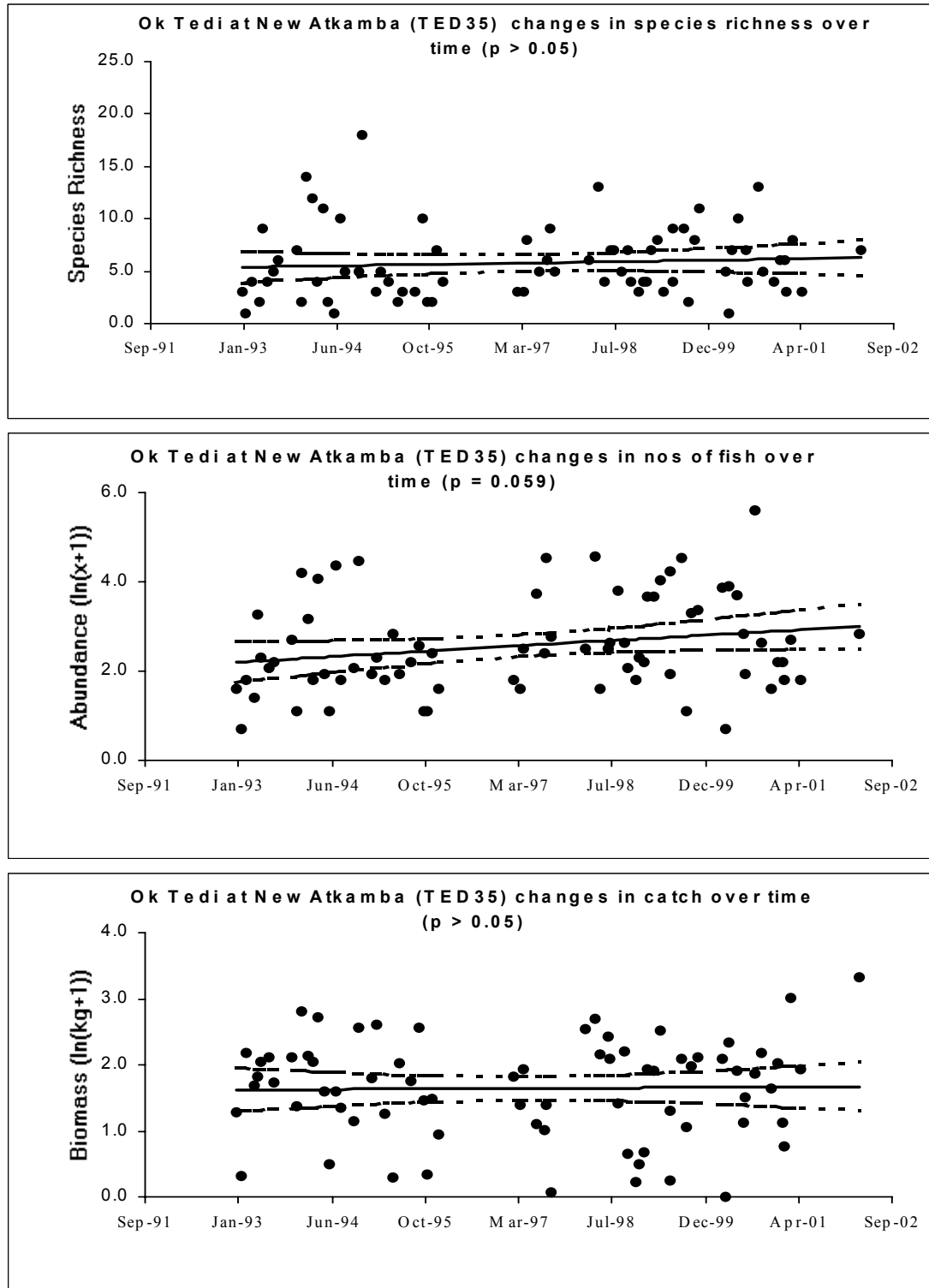
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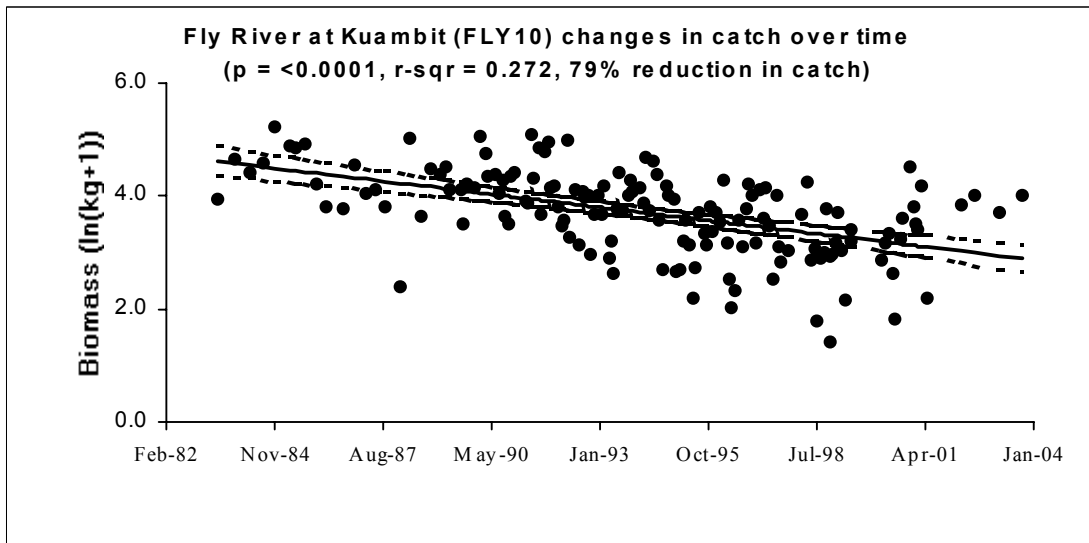
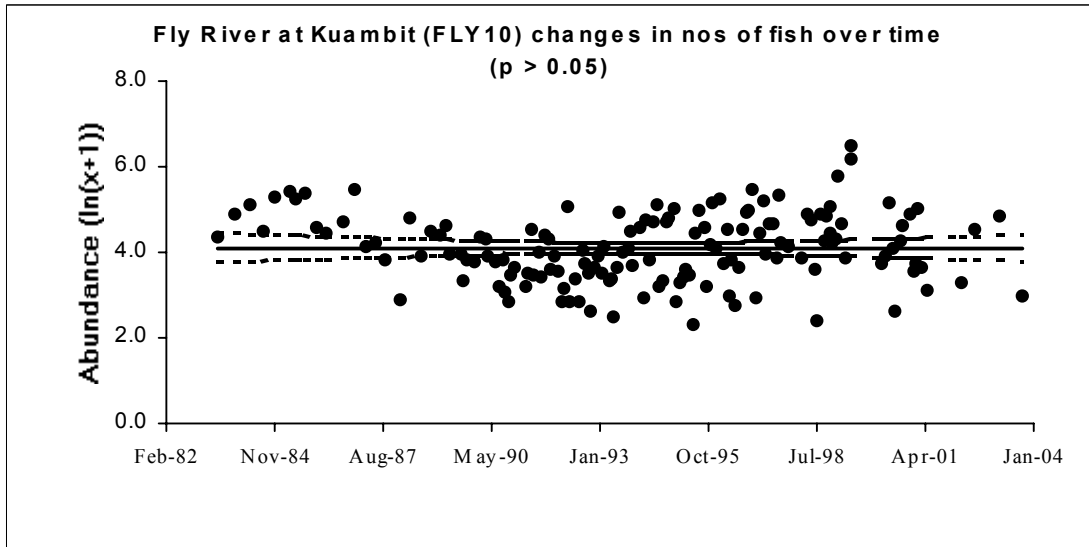
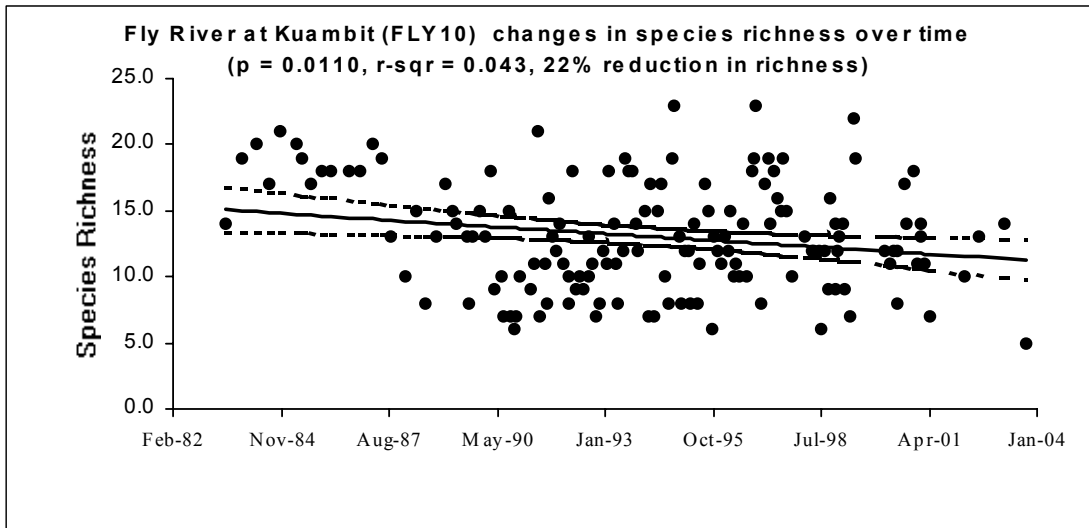
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Appendices

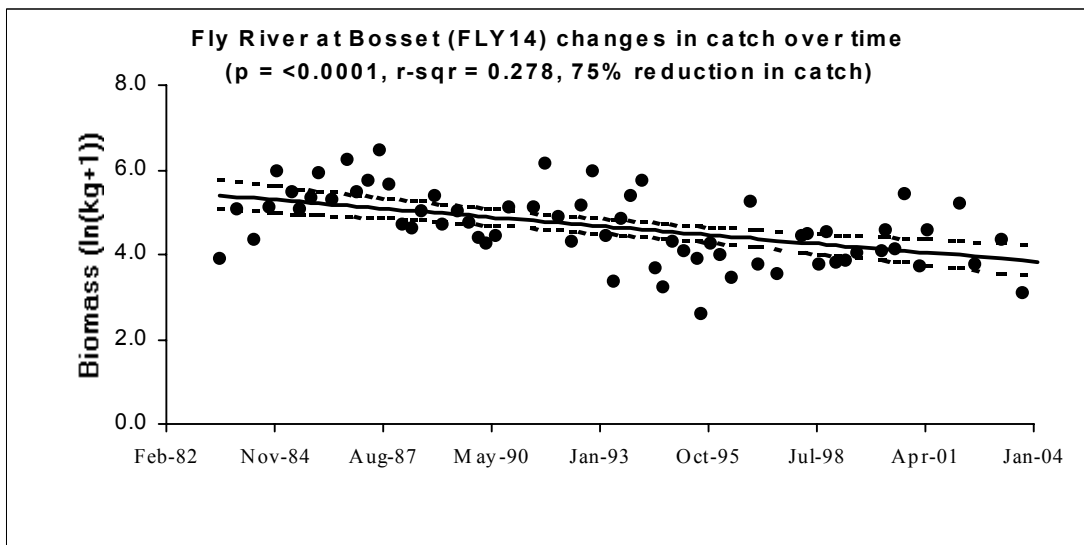
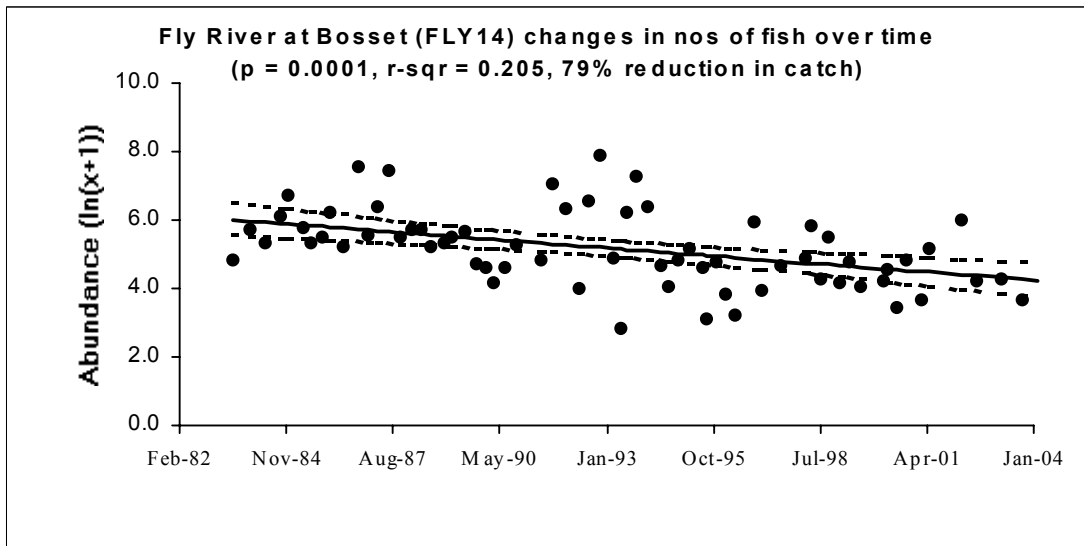
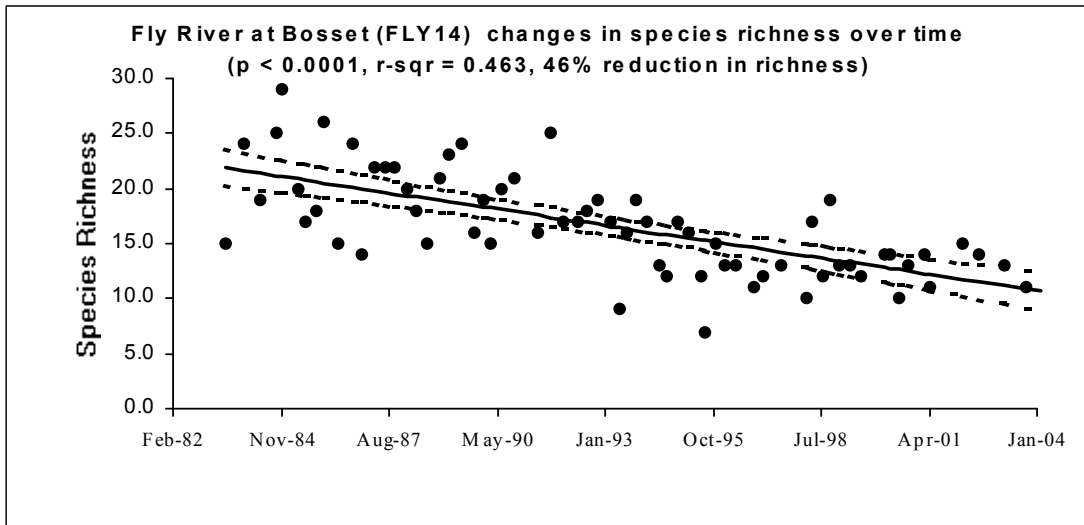
Appendix 1. Changes in richness, abundance and biomass of fish at each site from commencement of sampling to current, showing linear regression of catch parameter against time, with significance of the regression, and where significant, r-squared value and percent change in catch.



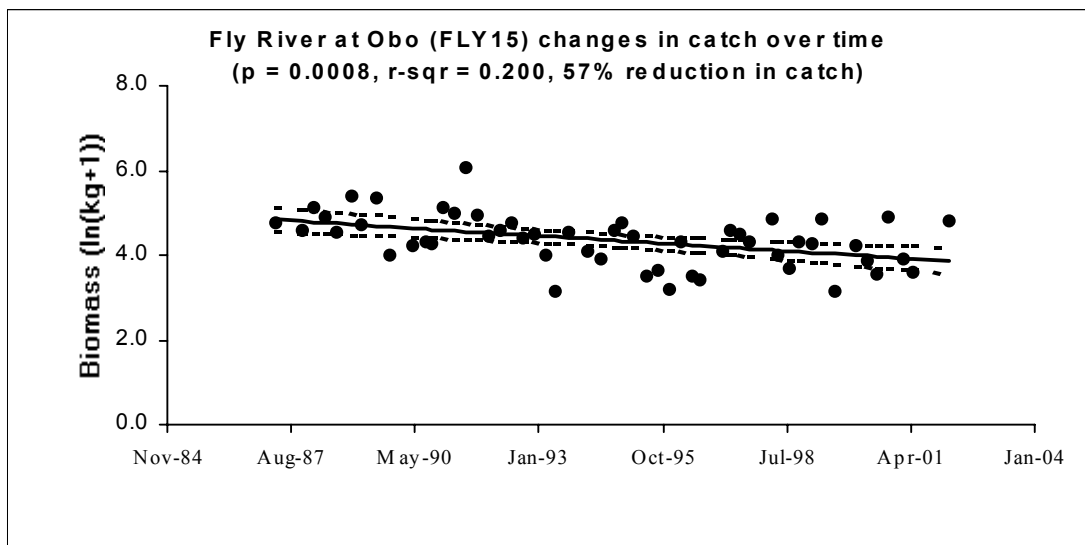
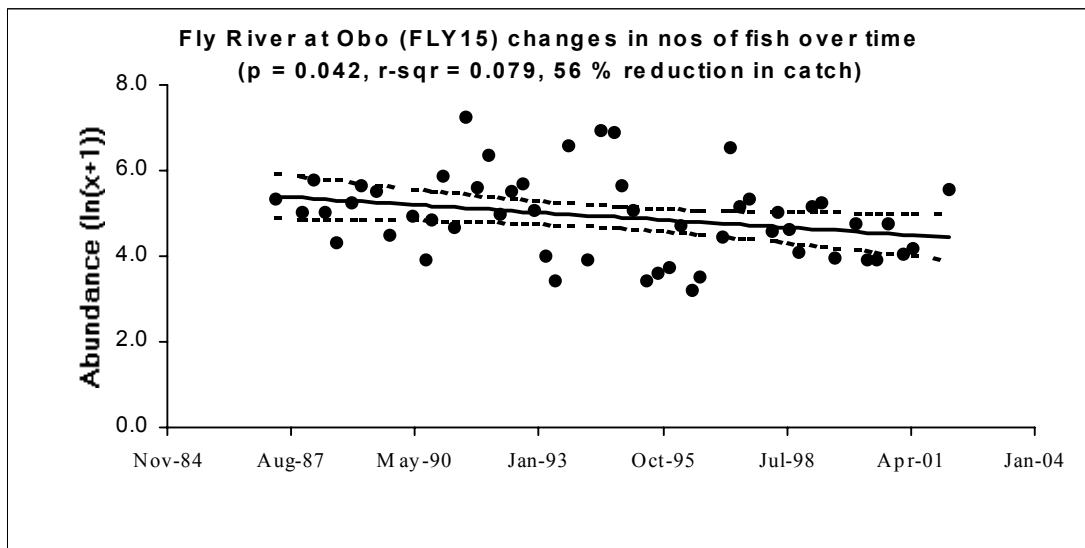
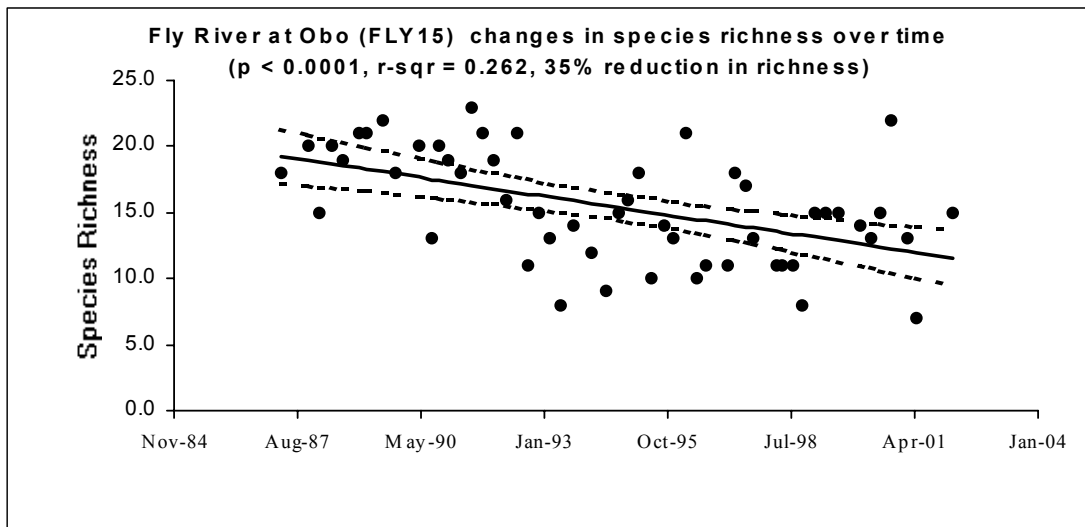
Appendix 1a. Temporal changes in species richness, abundance and biomass at New Atkamba (TED35).



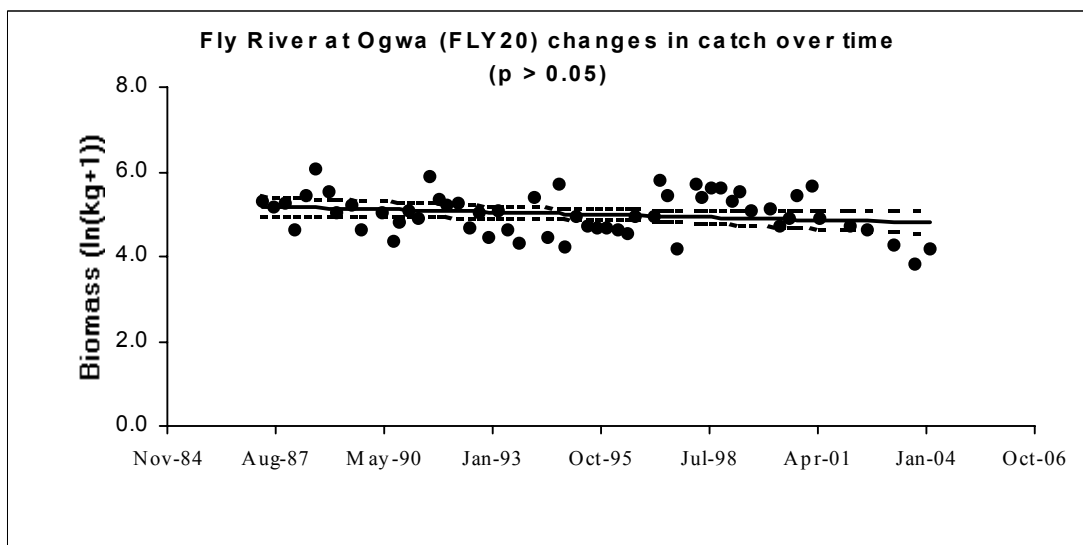
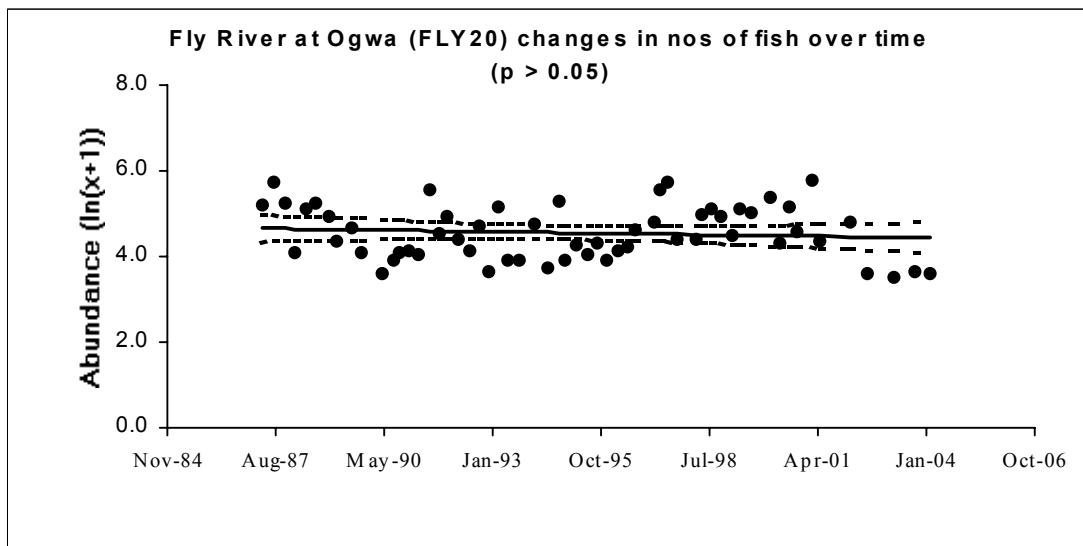
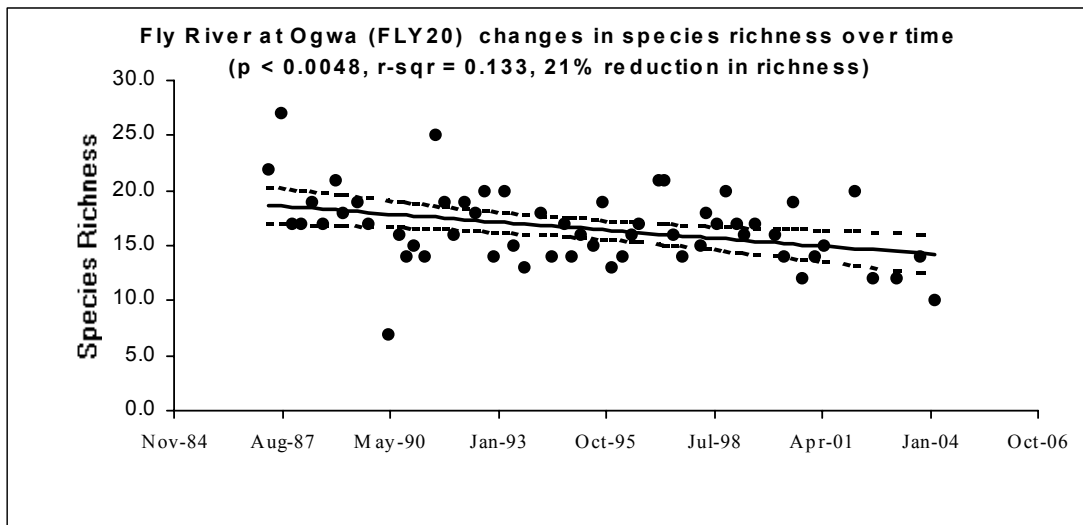
Appendix 1b. Temporal changes in species richness, abundance and biomass at Kuambit (FLY10).



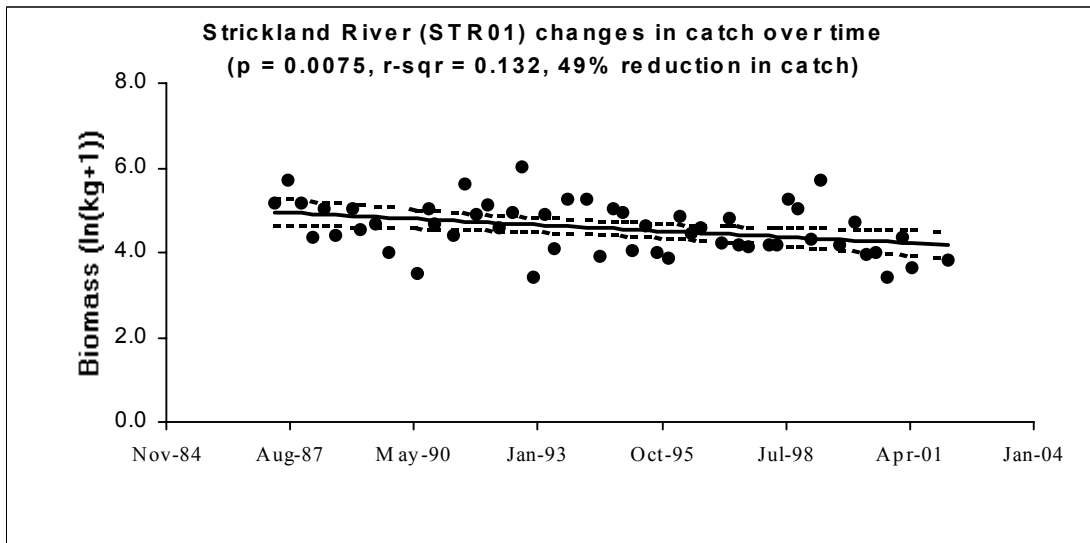
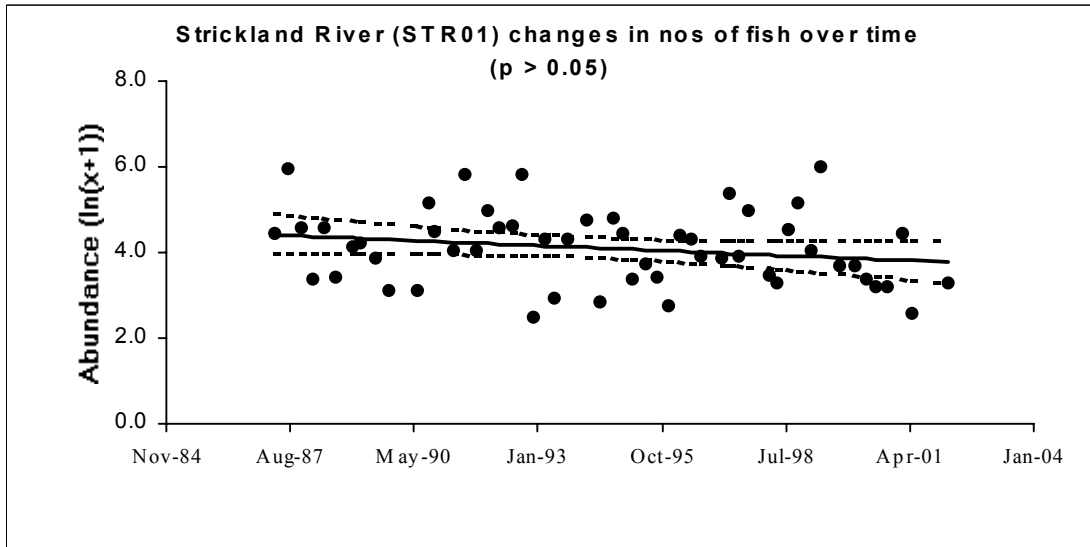
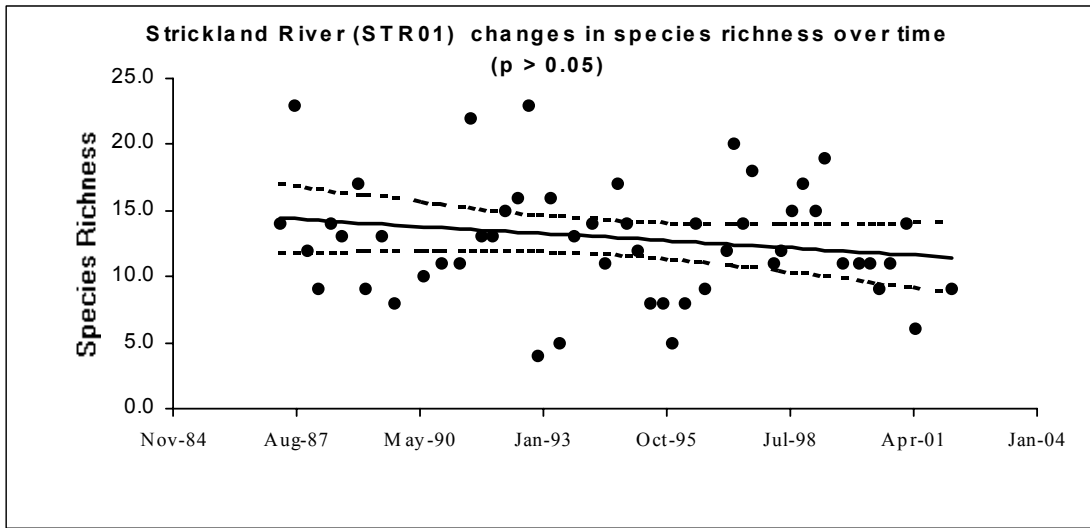
Appendix 1c. Temporal changes in species richness, abundance and biomass at Bosset (FLY14).



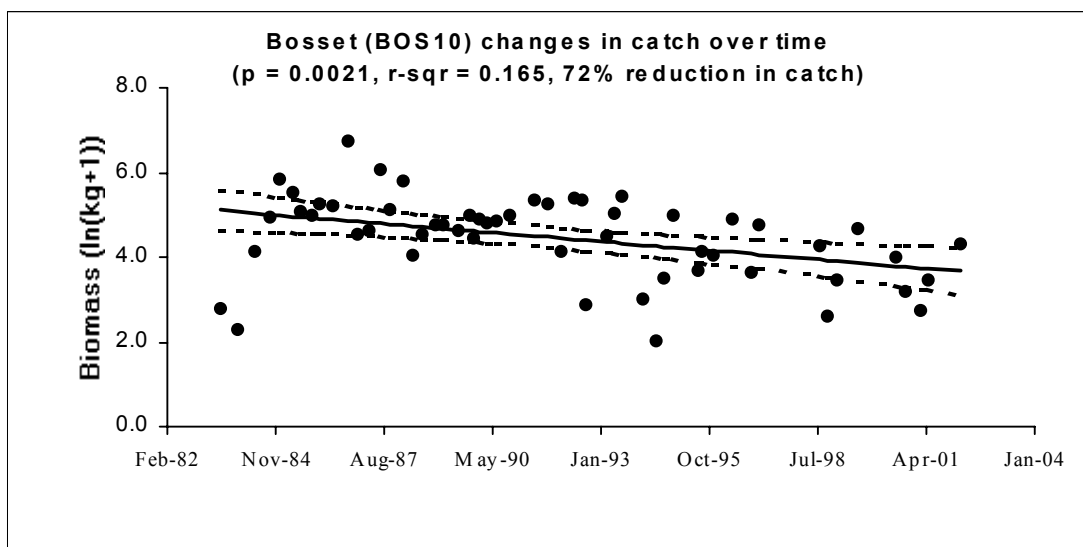
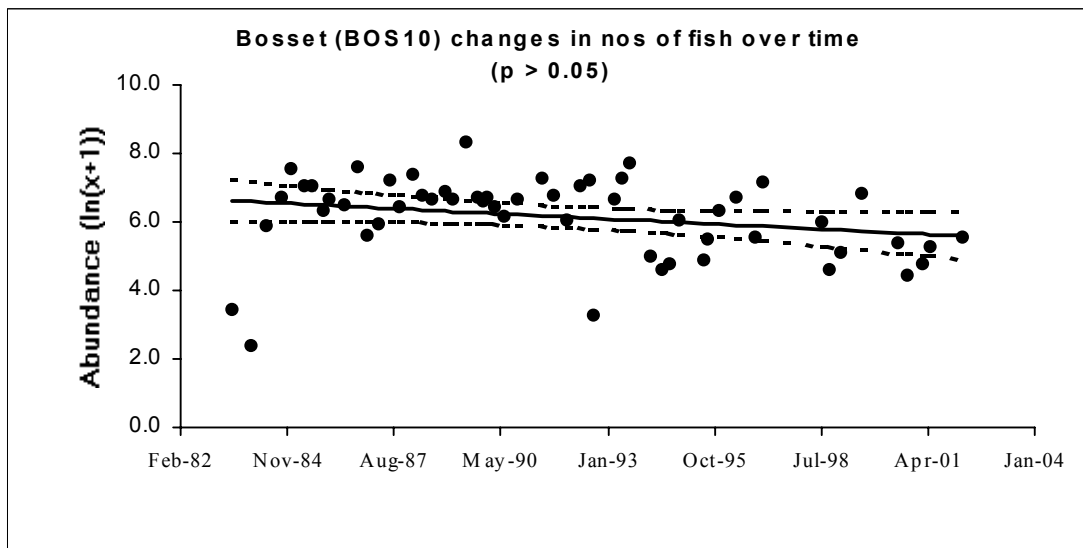
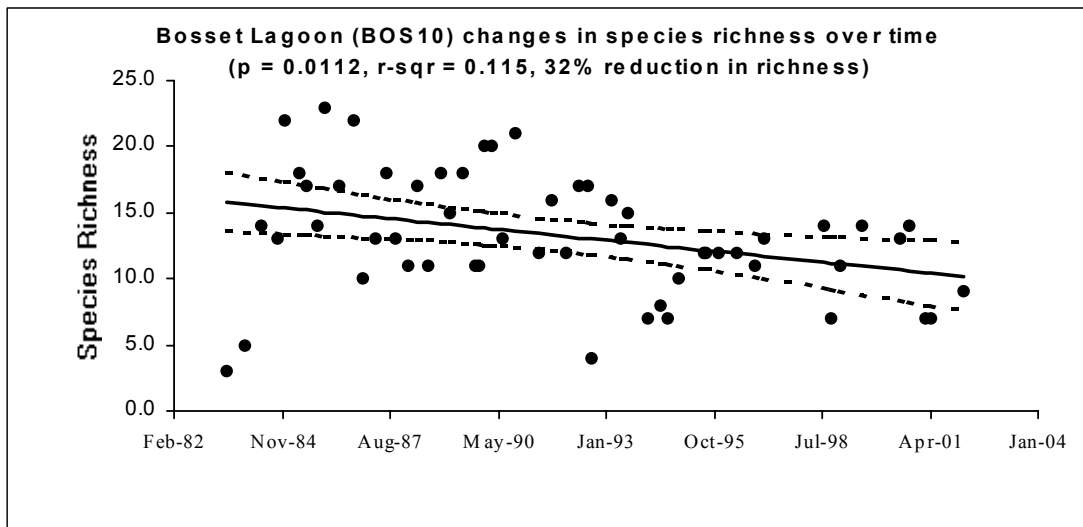
Appendix 1d. Temporal changes in species richness, abundance and biomass at Obo (FLY15).



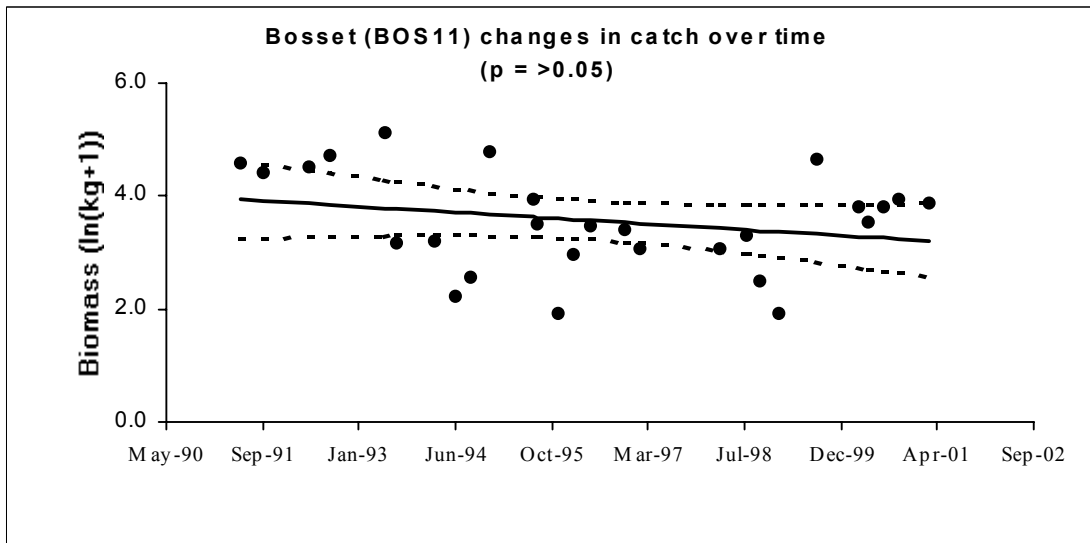
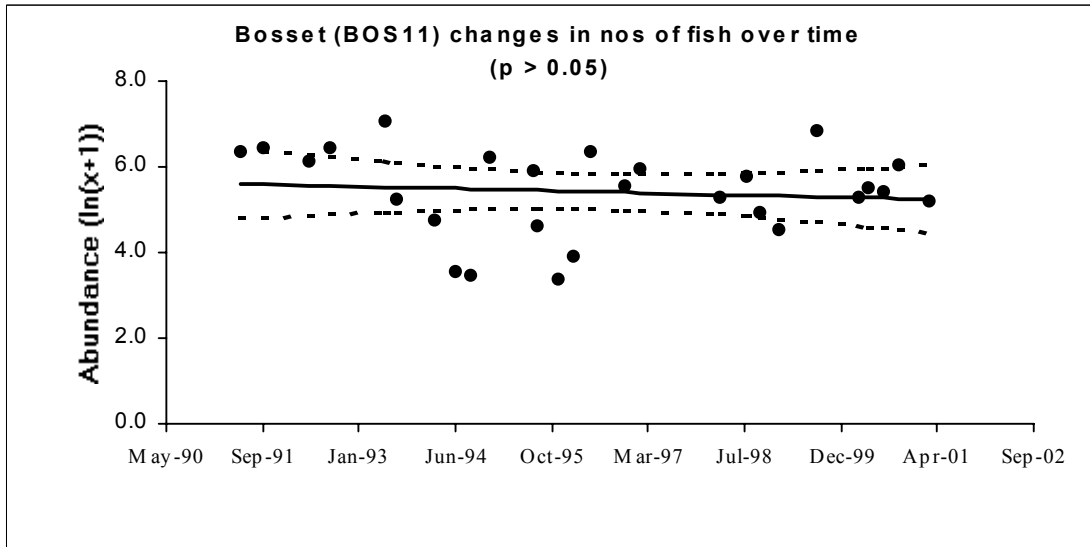
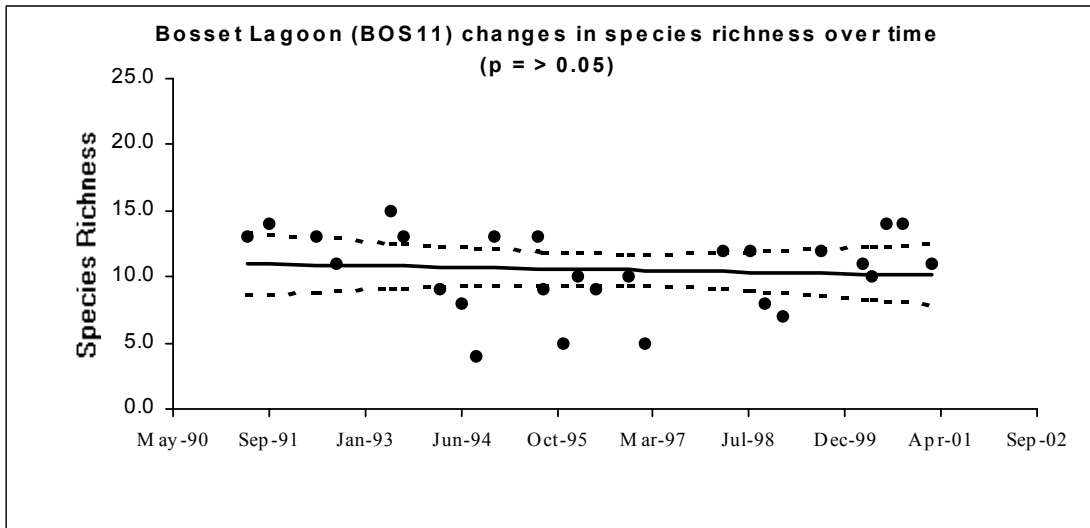
Appendix 1e. Temporal changes in species richness, abundance and biomass at Ogwa (FLY20).



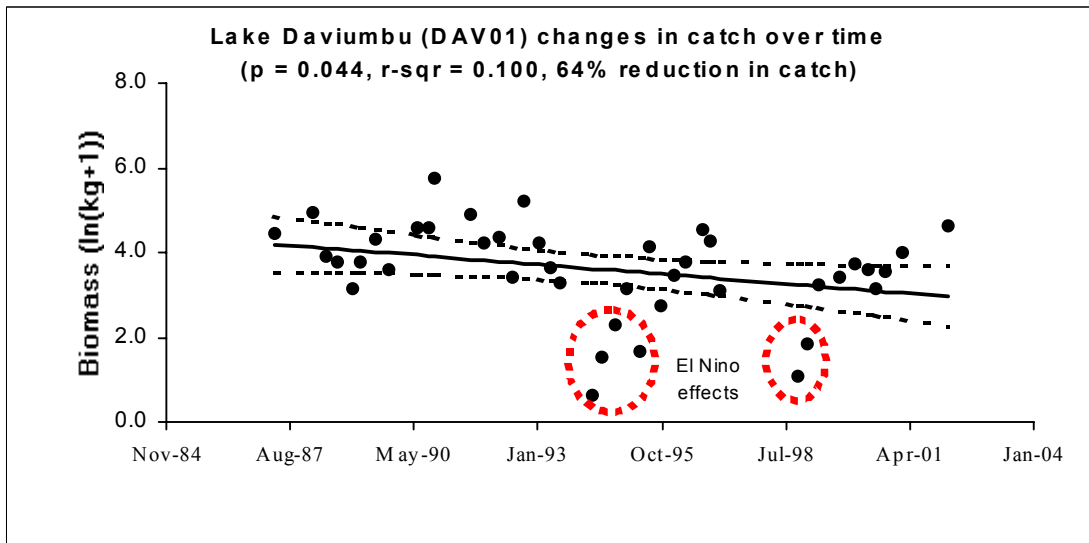
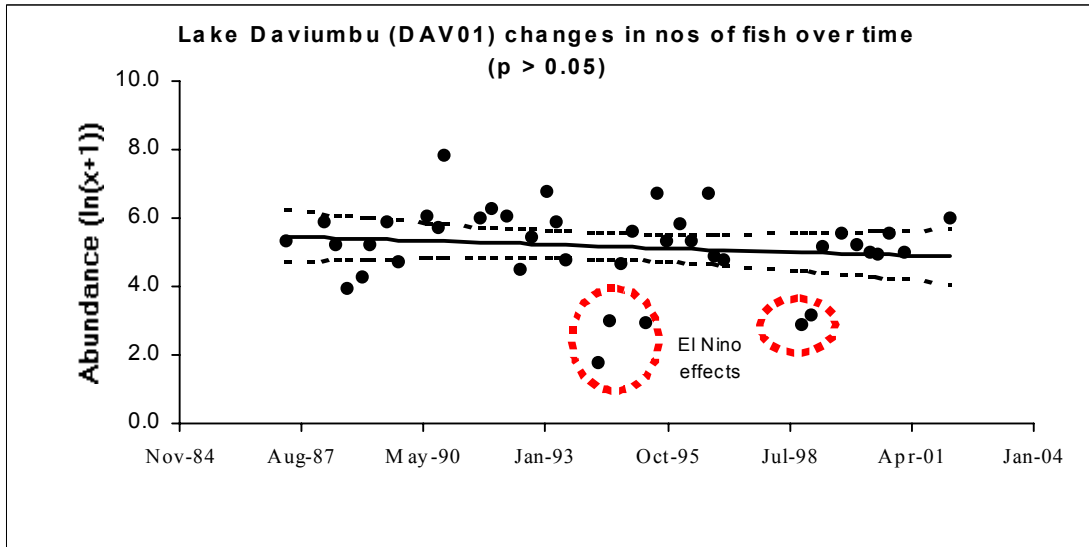
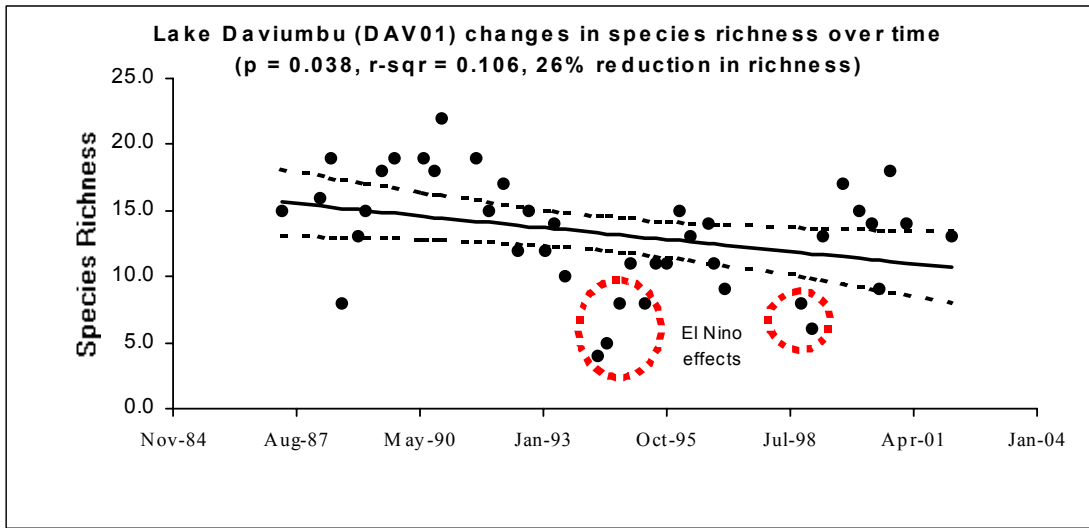
Appendix 1f. Temporal changes in species richness, abundance and biomass at Strickland River (STR01).



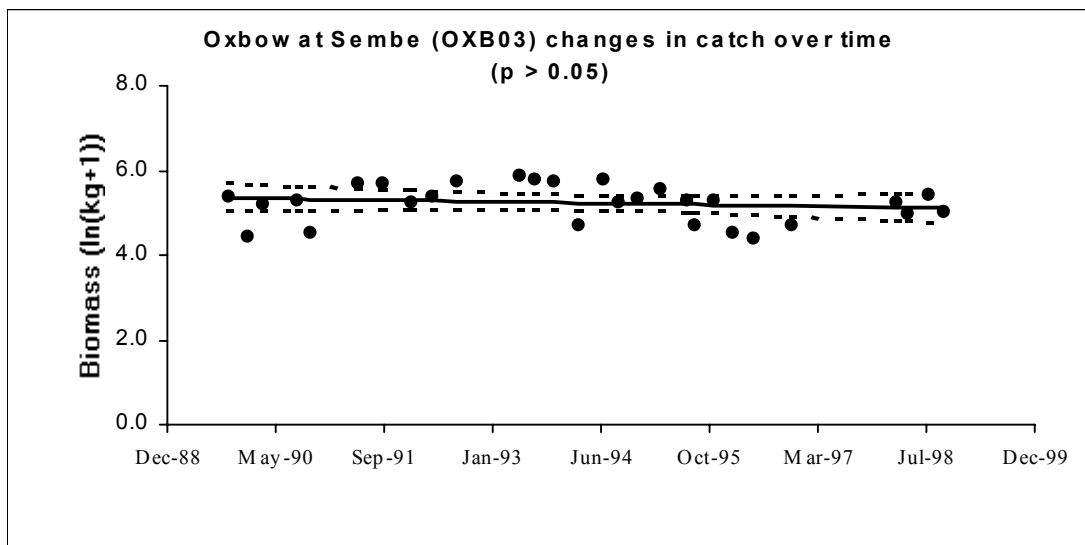
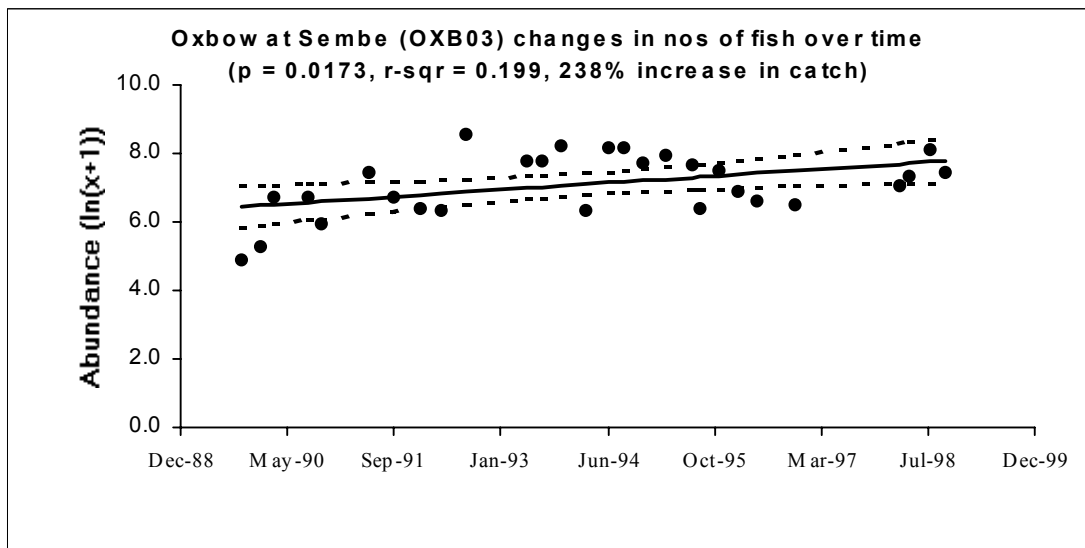
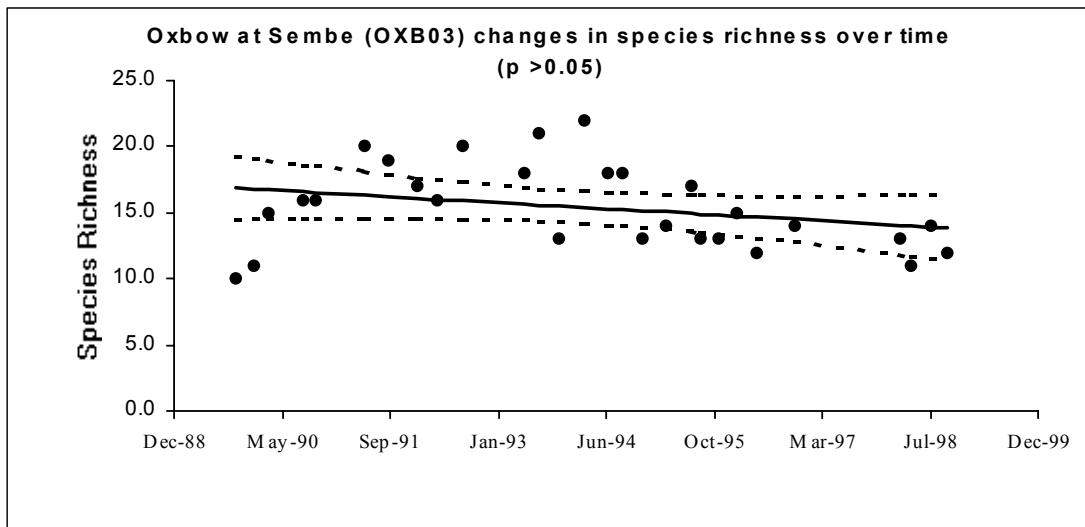
Appendix 1g. Temporal changes in species richness, abundance and biomass at Bosset Lagoon (BOS10).



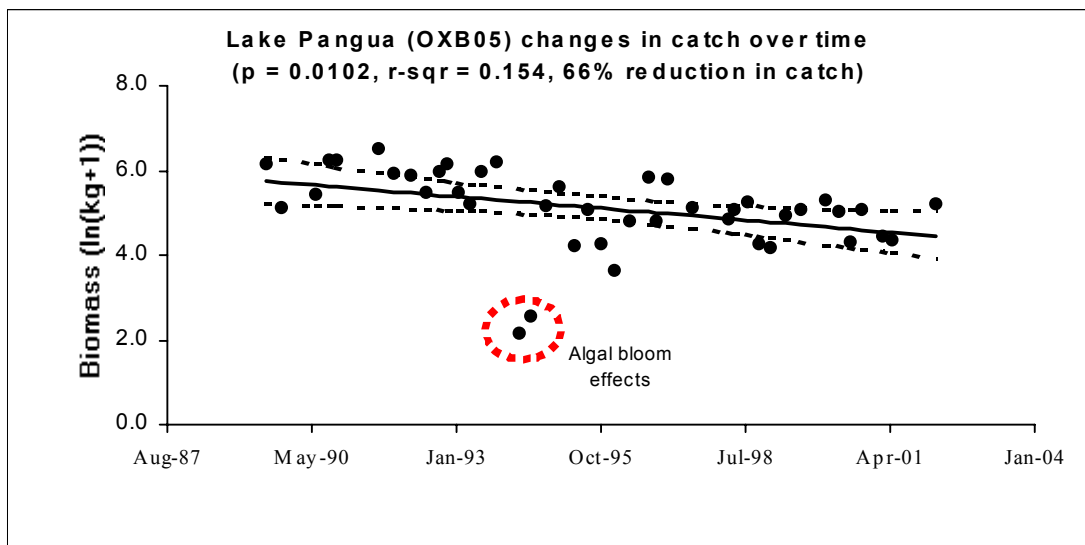
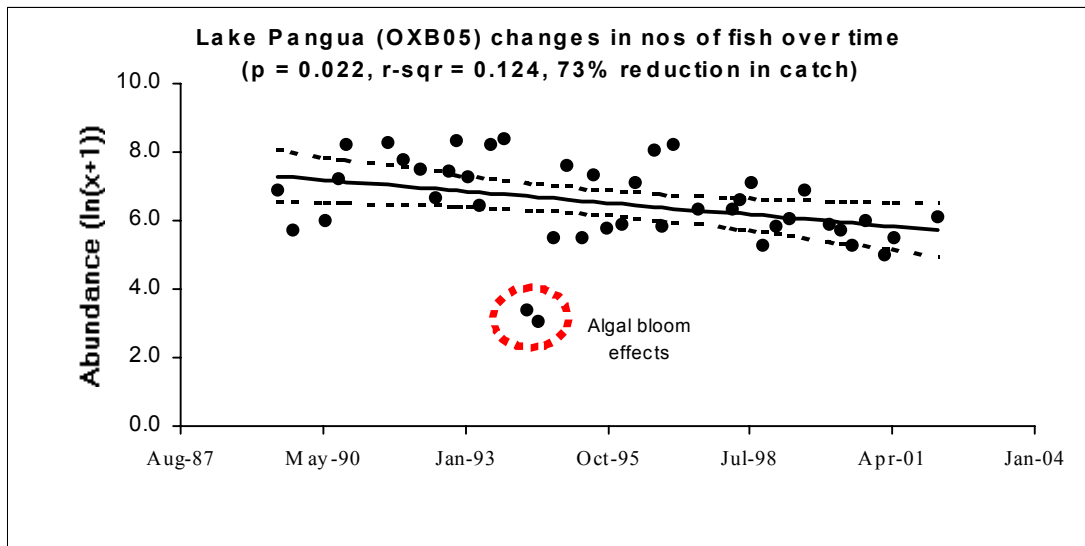
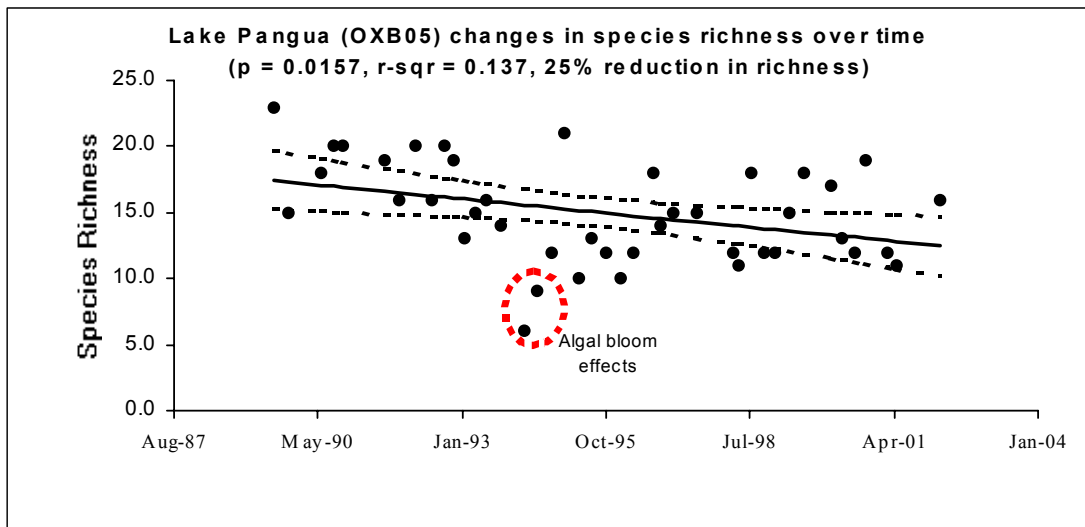
Appendix 1h. Temporal changes in species richness, abundance and biomass at Bosset Lagoon (BOS11).



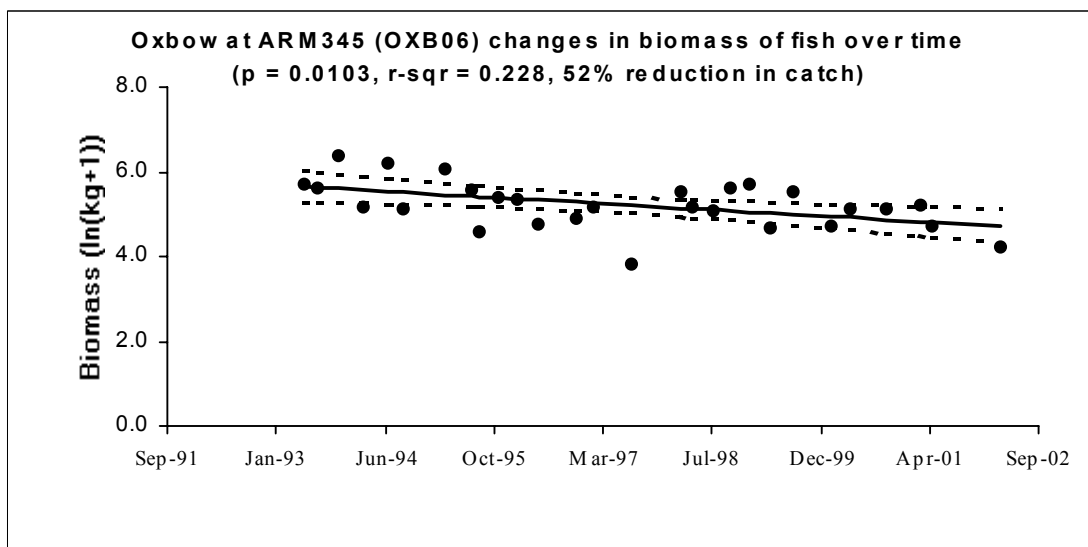
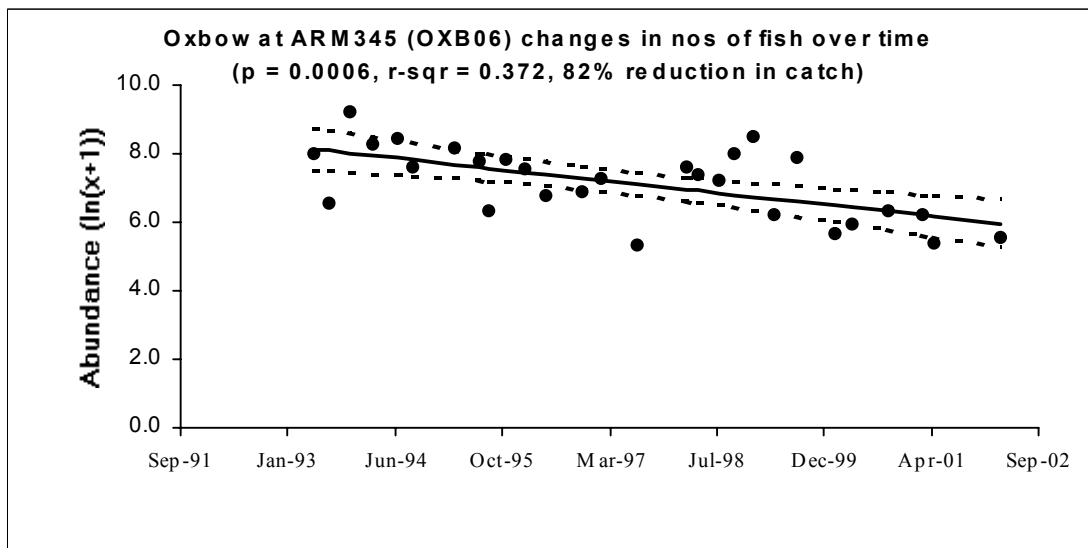
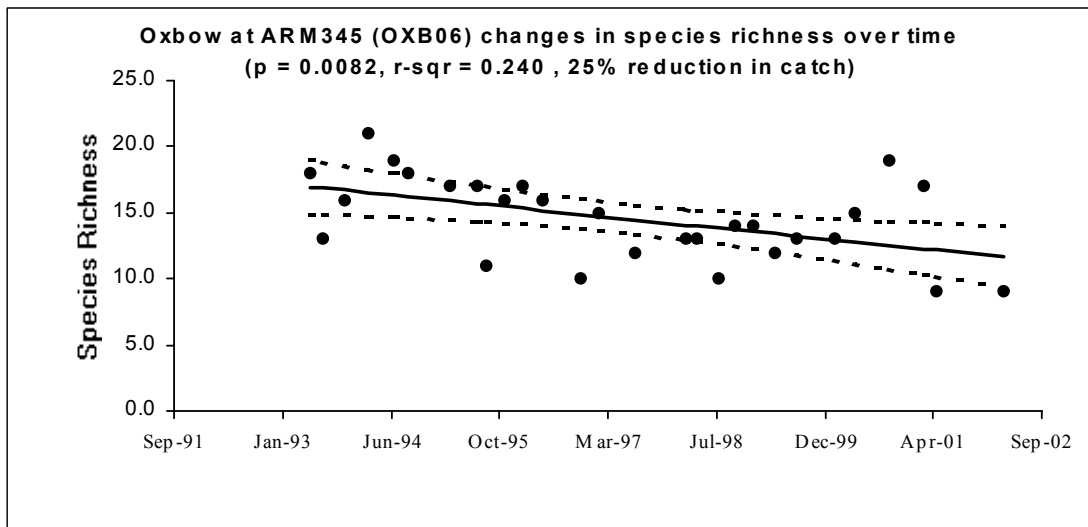
Appendix 1i. Temporal changes in species richness, abundance and biomass at Lake Daviumbu (DAV01), indicating samples affected by El Nino droughts.



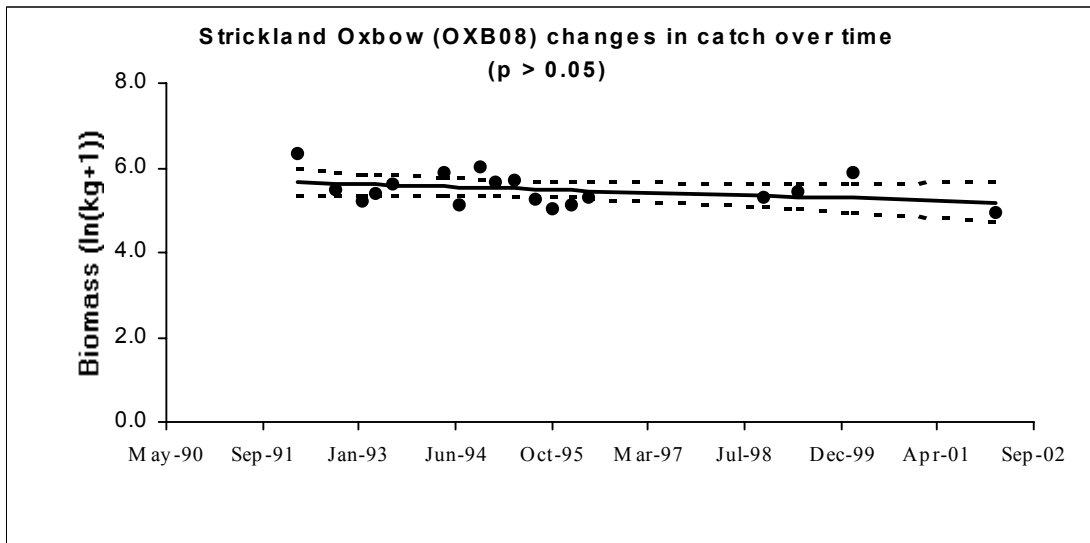
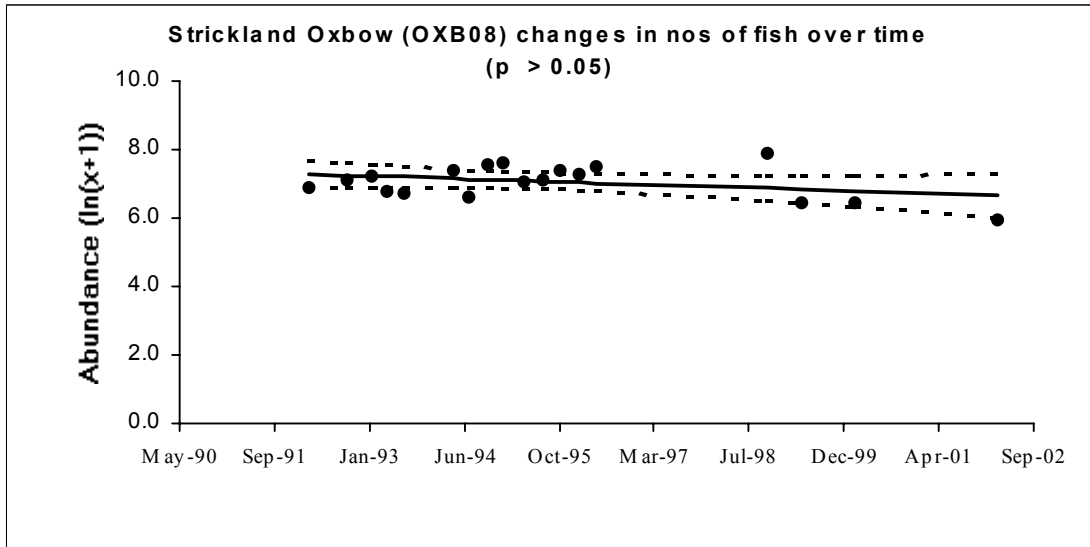
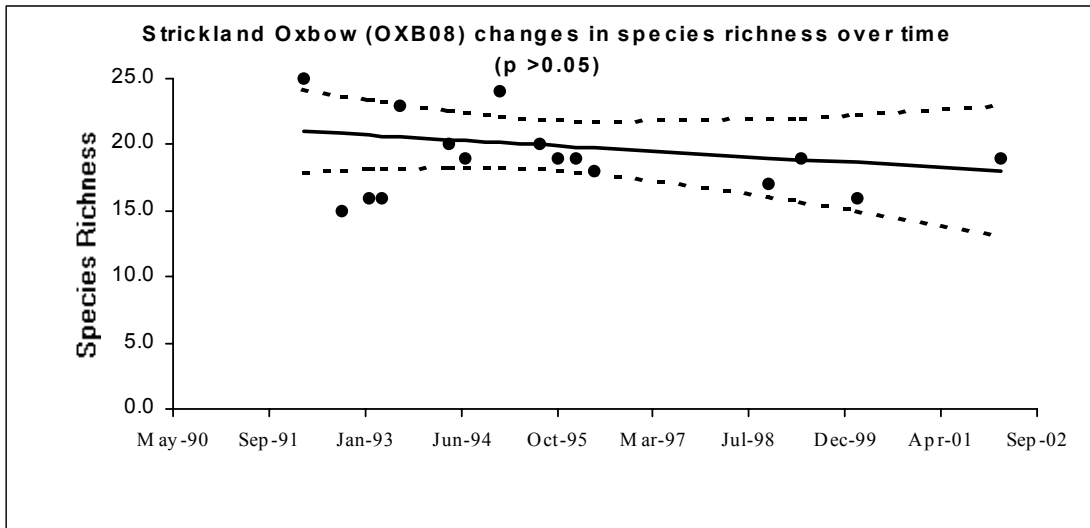
Appendix 1j. Temporal changes in species richness, abundance and biomass at Sembe Oxbow (OXB03).



Appendix 1k. Temporal changes in species richness, abundance and biomass at Lake Pangua (OXB05).



Appendix 1I. Temporal changes in species richness, abundance and biomass at Oxbow at ARM345 (OXB06).



Appendix 1m. Temporal changes in species richness, abundance and biomass at Strickland Oxbow (OXB08).