

Analyses of data from marine benthic
monitoring around the proposed outfall of the
Gunns Pulp Mill
Report prepared for Aquenal Pty Ltd

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Contents

1	Introduction and aims	1
1.1	Introduction	1
1.2	Aims	1
2	Methods	2
3	Results	4
3.1	Benthic infauna	4
3.2	Epibiota (benthic algae)	10
3.3	Fish	22
4	Discussion and conclusions	30

1 Introduction and aims

1.1 Introduction

Data have now been collected from four sampling dates (Autumn 2005, Spring 2005, Winter 2006, Spring 2006) from 12 Locations around the initial proposed outfall for the proposed Gunns Pulp Mill. It has been proposed that the site of the outfall be shifted inshore, and this will result in moving the Locations that have been surveyed up until the end of 2006. Accordingly, the data collected thus far will not be used in formal analyses in the final marine benthic monitoring program. However, this large and comprehensive data set provides an excellent opportunity to provide a qualitative appraisal of the strengths and risks involved in implementing an MBACI monitoring design at the newly proposed outfall site.

1.2 Aims

As a result, the aims of these analyses were:

1. Determine whether there were any spatial differences between Impact Locations and Inner and Outer Control Locations.
2. Test for temporal differences for selected response variables using the full data set from all sampling dates processed up to February 2007.
3. Provide a general assessment of the likely success of implementing a monitoring program based on MBACI principles.

Full descriptions of the rationale of the monitoring design and layout have been given in previous Aquenal reports. The nomenclature remains the same as in those reports.

2 Methods

As for the previous Aquenal reports, data were aggregated by averaging to the Site stratum in the design for all data sets. If any transformations were used, these were applied before aggregation, except for the total abundance and species richness of fish, which had substantial numbers of zeroes in the Replicate stratum. Where transformations were used, these are identified explicitly in the results. Note that in previous Aquenal reports, transformations were not generally applied to the univariate analyses presented in those reports. Accordingly, some of the features noted in those previous reports may not be reiterated in this set of analyses.

Overall, the rationale of these analyses was chiefly exploratory rather than confirmatory, since the Locations are to be moved to accommodate the proposed relocation of the outfall. Thus, no attempt has been made to pursue more complicated, spatially explicit statistical models for this data set. Instead, the main analyses have used a “repeated measures” approach using ordinary least squares methods so that the analyses are consistent with those elaborated by Keough and Mapstone, and used in previous Aquenal reports.

The first two aims were achieved by treating the Locations as “subjects” within which Sites were nested (and acted as subsamples). Sample date was the “within subjects” factor (four levels: Autumn 2005, Spring 2005, Winter 2006, Spring 2006), and Location type (three levels: Impact, Inner Control, Outer Control) was the “between subjects” factor. Pre-planned contrasts were used within each stratum to address the specific questions of Aims 1 and 2. Accordingly, the ANOVA tables that are presented here are divided into two strata, with terms and their interpretations as follows:

Between Locations contains the test for the (fixed) effect of Location Type. This term was then split into two contrasts: Impact Locations v. Inner Controls and Impact Locations v. Outer Controls. These tests address Aim 1.

Within Locations contains the tests for an overall effect of sampling date (hereafter termed “Date”) and the interaction between sampling date and Location Type (i.e. Date \times Location Type). The Date factor was further split up into three contrasts as follows:

Spring 2005 v. Spring 2006 tests whether the two Spring sample dates differed.

Autumn 2005 v. Winter 2006 tests whether these two sample dates differed; there has been some concern that the Winter sample date might deviate substantially from the preferred Autumn sample dates envisaged in the final monitoring program

Spring dates v. the other two dates While the potential deviation of Winter from Autumn should be kept in mind, this contrast provides a coarse indication of likely seasonality in the chosen response variables.

The interaction term may also be broken down into the contrasts implied by those for the Location Type and Date factors, but none of these were remotely significant for any of the variables examined, except for the percent cover of red algae (Table 7, and so this level of detail has been omitted from the ANOVA tables presented in this document. However, if there were significant Date \times Location Type terms, this would imply that at least one set of Locations had a different trajectory over time: this is potentially a serious problem for MBACI designs since asynchronous behaviour over time amongst control locations weakens the power of the tests used to infer impacts.

For each response variable, means are tabulated, and boxplots are presented to summarize effects. In addition, scatterplots over time with separate panels for each Location are presented to allow some qualitative assessment of the likely potential for Locations that behave aberrantly or have outlying values. While these figures are not often referred to explicitly in the text of this document, they are included as they may prove useful in further planning the final monitoring program. Although there are some formal test procedures for examining synchrony, the short time-series (only 4 sample dates) of this data set precludes meaningful use of these techniques.

3 Results

3.1 Benthic infauna

For log total abundance, there was some very weak evidence that the Inner Controls had greater abundances than the Impact Locations, but there were no statistically defensible effects of sample date (Table 1, Figure 1). There was a much stronger contrast between Inner Controls and Impact Locations for species richness, with Inner Controls supporting more species than Impact locations (Figure 3), while the only significant time-related difference was the lower species richness of Winter 2006 than Autumn 2005 for all Location types (Table 3; Figure 3). and a weak potential quadratic trend with time.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Between Locations					
LocType	2	5.56	2.78	1.93	0.201
Inner	1	4.99	4.99	3.46	0.096
Outer	1	0.57	0.57	0.40	0.544
Residuals	9	12.99	1.44		
Within Locations					
Date	3	8.44	2.81	1.30	0.294
SvS	1	0.27	0.27	0.13	0.725
AvW	1	5.34	5.34	2.47	0.128
SvAW	1	2.82	2.82	1.30	0.263
LocType×Date	6	7.87	1.31	0.61	0.723
Residuals	27	58.41	2.16		

Table 1: ANOVA of log-transformed total abundance. “LocType” is the type of Location, and the rows labelled “Inner” and “Outer” report the contrasts with the Impact Locations. “SvS” contrasts the two spring sample dates; “AvW” contrasts Autumn 2005 with Winter 2006; “SvAW” contrasts the average value of the spring dates with the average of the Autumn 2005 and Winter 2006 dates.

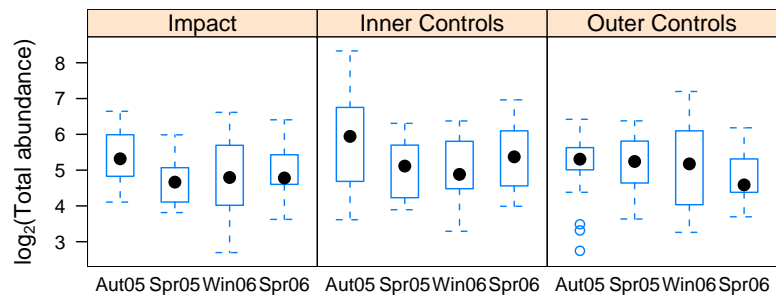


Figure 1: Boxplots of log-transformed total abundance of infauna plotted as a function of sample date for each type of Location. Large black dots denote the median.

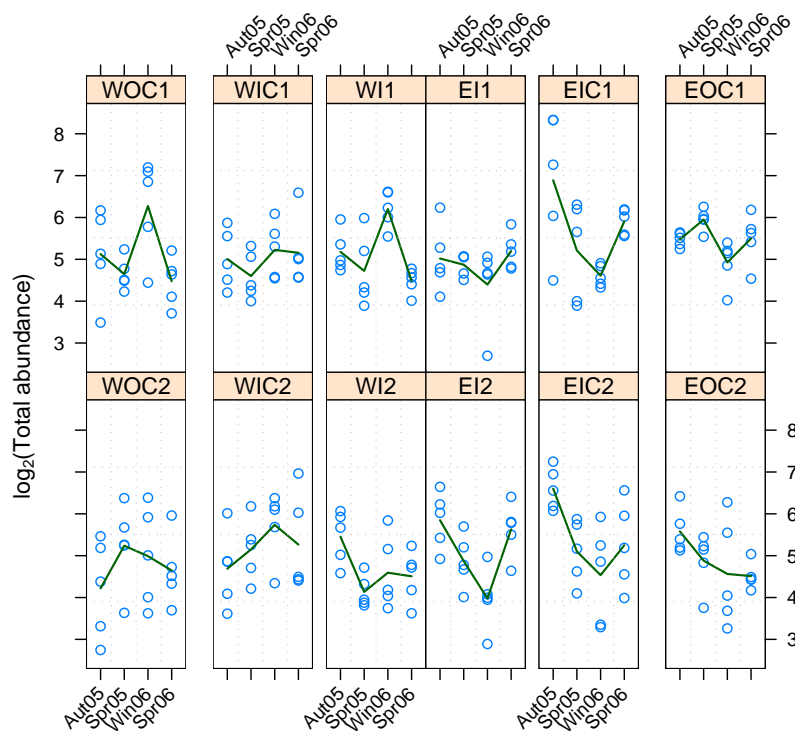


Figure 2: Log-transformed total abundance of infauna plotted as a function of sample date. Location abbreviations follow those of previous Aquenal reports. Each symbol denotes the value of a Site within each Location; the line in each panel connects the means on each sample date.

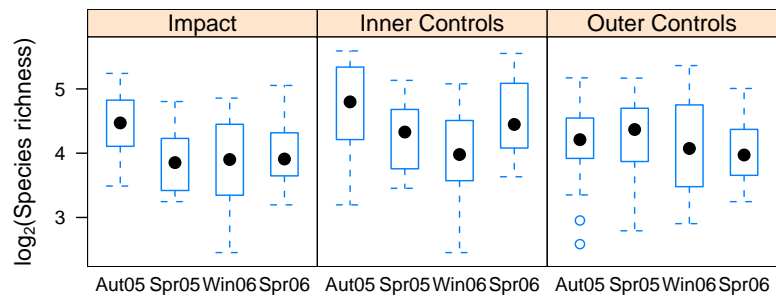


Figure 3: Boxplots of log-transformed species richness of infauna plotted as a function of sample date for each type of Location. Large black dots denote the median.

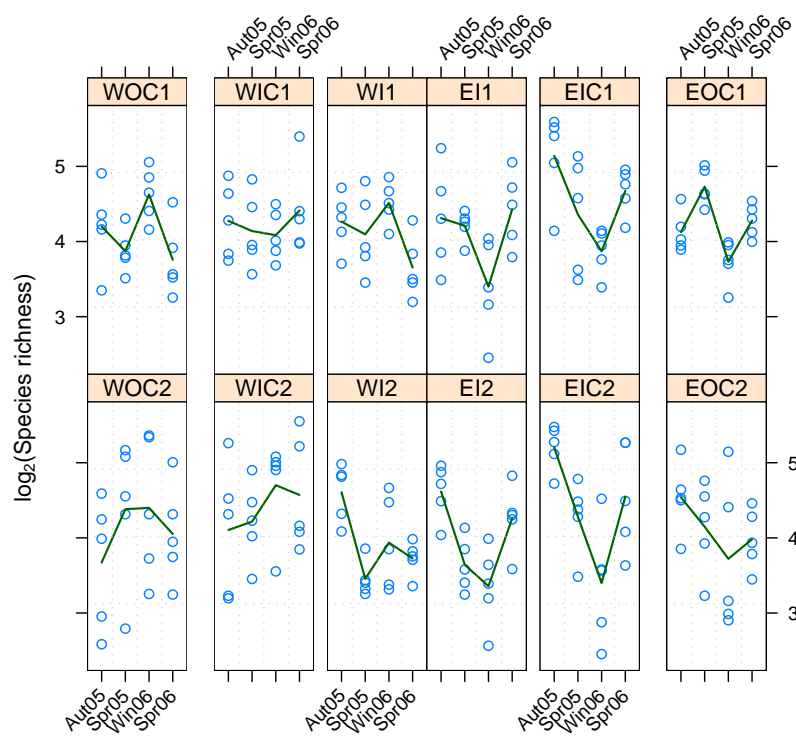


Figure 4: Log-transformed species richness of infauna plotted as a function of sample date. Location abbreviations follow those of previous Aquenal reports. Each symbol denotes the value of a Site within each Location; the line in each panel connects the means on each sample date.

	Aut05	Spr05	Win06	Spr06	LocType
Impact	5.375	4.650	4.792	4.954	4.943
Inner Controls	5.797	5.016	5.026	5.394	5.308
Outer Controls	5.100	5.179	5.188	4.783	5.062
Date	5.424	4.948	5.002	5.044	

Table 2: \log_2 -transformed total abundance means

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Between Locations					
LocType	2	4.95	2.48	14.55	0.002
Inner	1	4.48	4.48	26.31	0.001
Outer	1	0.47	0.47	2.79	0.129
Residuals	9	1.53	0.17		
Within Locations					
Date	3	6.13	2.04	2.21	0.110
SvS	1	0.14	0.14	0.15	0.705
AvW	1	5.91	5.91	6.39	0.018
SvAW	1	0.09	0.09	0.10	0.757
LocType×Date	6	5.23	0.87	0.94	0.481
Residuals	27	24.97	0.92		

Table 3: ANOVA of log-transformed infaunal species richness. “LocType” is the type of Location, and the rows labelled “Inner” and “Outer” report the contrasts with the Impact Locations. “SvS” contrasts the two spring sample dates; “AvW” contrasts Autumn 2005 with Winter 2006; “SvAW” contrasts the average value of the spring dates with the average of the Autumn 2005 and Winter 2006 dates.

	Aut05	Spr05	Win06	Spr06	LocType
Impact	4.450	3.851	3.801	4.016	4.030
Inner Controls	4.681	4.249	4.014	4.551	4.374
Outer Controls	4.134	4.283	4.119	4.017	4.138
Date	4.422	4.128	3.978	4.195	

Table 4: \log_2 -transformed species richness means for benthic infauna

3.2 Epibiota (benthic algae)

All these analyses were based on the old sampling protocol, which resulted in a substantial proportion of quadrats landing on habitat unsuitable for epibiota. Accordingly, the diagnostic plots from these analyses generally showed departures from normality, albeit not very strong departures. Nevertheless, the p -values should be treated with some caution because of these problems.

Inner Controls, again, seemed to have greater cover of total algae than Impact Locations, irrespective of sample date. Temporally, Spring 2006 supported better cover than Spring 2005, and Winter 2006 supported lower cover than Autumn 2005. Note that the Outer controls tended to have a high proportion of zero values, but this did not engender any significant interactions between Location type and sample date.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Between Locations					
LocType	2	18835.07	9417.54	4.55	0.043
Inner	1	16532.27	16532.27	7.99	0.020
Outer	1	2302.81	2302.81	1.11	0.319
Residuals	9	18630.98	2070.11		
Within Locations					
Date	3	4558.98	1519.66	4.49	0.011
SvS	1	1400.83	1400.83	4.14	0.052
AvW	1	2960.13	2960.13	8.74	0.006
SvAW	1	198.02	198.02	0.58	0.451
LocType×Date	6	1267.59	211.27	0.62	0.710
Residuals	27	9143.63	338.65		

Table 5: ANOVA of total cover by algae. “LocType” is the type of Location, and the rows labelled “Inner” and “Outer” report the contrasts with the Impact Locations. “SvS” contrasts the two spring sample dates; “AvW” contrasts Autumn 2005 with Winter 2006; “SvAW” contrasts the average value of the spring dates with the average of the Autumn 2005 and Winter 2006 dates.

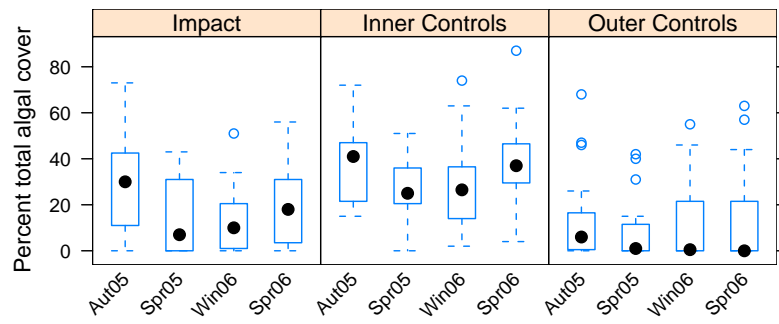


Figure 5: Boxplots of percentage cover by total algae plotted as a function of sample date for each type of Location. Large black dots denote the median.

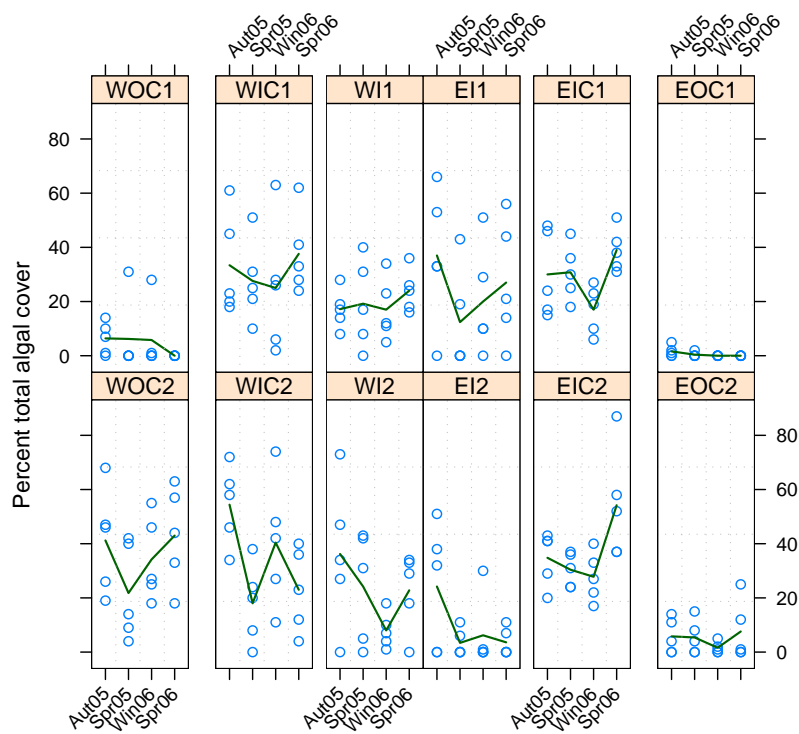


Figure 6: Percent cover by total algae plotted as a function of sample date. Location abbreviations follow those of previous Aquenal reports. Each symbol denotes the value of a Site within each Location; the line in each panel connects the means on each sample date.

	Aut05	Spr05	Win06	Spr06	LocType
Impact	28.65	14.80	12.80	19.35	18.90
Inner Controls	38.15	26.70	27.55	38.45	32.71
Outer Controls	13.75	8.45	10.40	12.65	11.31
Date	26.850	16.650	16.917	23.483	

Table 6: Total algal cover means

By contrast, red algae showed a strong interaction between Location Type and Date (Table 7), and it is clear that the percentage cover of this taxon was so low in some of the Outer Controls that the trends over time differed between the Location Types (Figure 8). As with total algal cover, Inner Controls tended to have greater cover than Impact Locations (Figure ??

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Between Locations					
LocType	2	2127.47	1063.74	1.36	0.305
Inner	1	1665.07	1665.07	2.13	0.179
Outer	1	462.40	462.40	0.59	0.462
Residuals	9	7039.04	782.12		
Within Locations					
Date	3	3739.41	1246.47	17.17	<0.001S
SvS	1	957.67	957.67	13.19	0.001
AvW	1	1216.03	1216.03	16.75	<0.001
SvAW	1	1565.70	1565.70	21.57	<0.001
LocType×Date	6	1504.63	250.77	3.45	0.012
Residuals	27	1960.01	72.59		

Table 7: ANOVA of percent cover by red algae. “LocType” is the type of Location, and the rows labelled “Inner” and “Outer” report the contrasts with the Impact Locations. “SvS” contrasts the two spring sample dates; “AvW” contrasts Autumn 2005 with Winter 2006; “SvAW” contrasts the average value of the spring dates with the average of the Autumn 2005 and Winter 2006 dates.

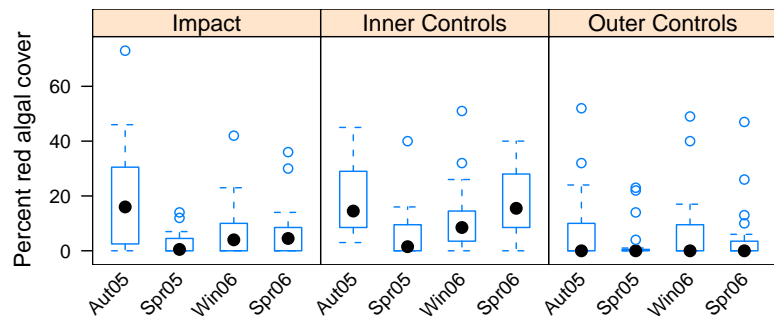


Figure 7: Boxplots of percentage cover by red algae plotted as a function of sample date for each type of Location. Large black dots denote the median.

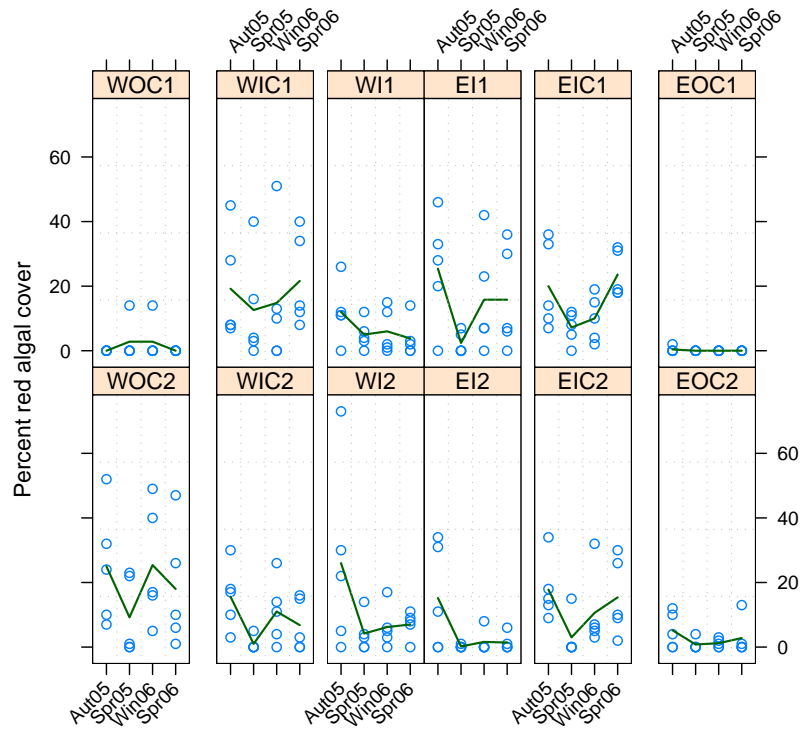


Figure 8: Percent cover by red algae plotted as a function of sample date. Location abbreviations follow those of previous Aquenal reports. Each symbol denotes the value of a Site within each Location; the line in each panel connects the means on each sample date.

	Aut05	Spr05	Win06	Spr06	LocType
Impact	28.65	14.80	12.80	19.35	18.90
Inner Controls	38.15	26.70	27.55	38.45	32.71
Outer Controls	13.75	8.45	10.40	12.65	11.31
Date	26.850	16.650	16.917	23.483	

Table 8: Red algal cover means

By contrast with the red algae, cover by brown algae displayed no defensible differences over time, but was on average greater in Inner Controls than Impact Locations (Tables 9 & 10, Figure 9).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Between Locations					
LocType	2	4305.06	2152.53	5.57	0.027
Inner	1	3876.03	3876.03	10.03	0.011
Outer	1	429.02	429.02	1.11	0.319
Residuals	9	3477.59	386.40		
Within Locations					
Date	3	342.65	114.22	1.09	0.370
SvS	1	85.01	85.01	0.81	0.376
AvW	1	192.53	192.53	1.84	0.186
SvAW	1	65.10	65.10	0.62	0.437
LocType×Date	6	895.54	149.26	1.43	0.241
Residuals	27	2826.86	104.70		

Table 9: ANOVA of percent cover by brown algae. “LocType” is the type of Location, and the rows labelled “Inner” and “Outer” report the contrasts with the Impact Locations. “SvS” contrasts the two spring sample dates; “AvW” contrasts Autumn 2005 with Winter 2006; “SvAW” contrasts the average value of the spring dates with the average of the Autumn 2005 and Winter 2006 dates.

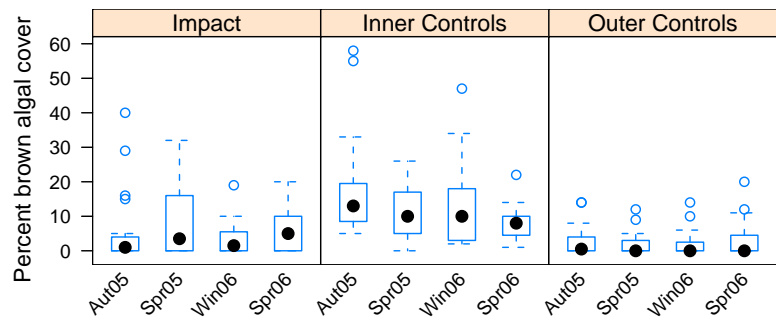


Figure 9: Boxplots of percentage cover by brown algae plotted as a function of sample date for each type of Location. Large black dots denote the median.

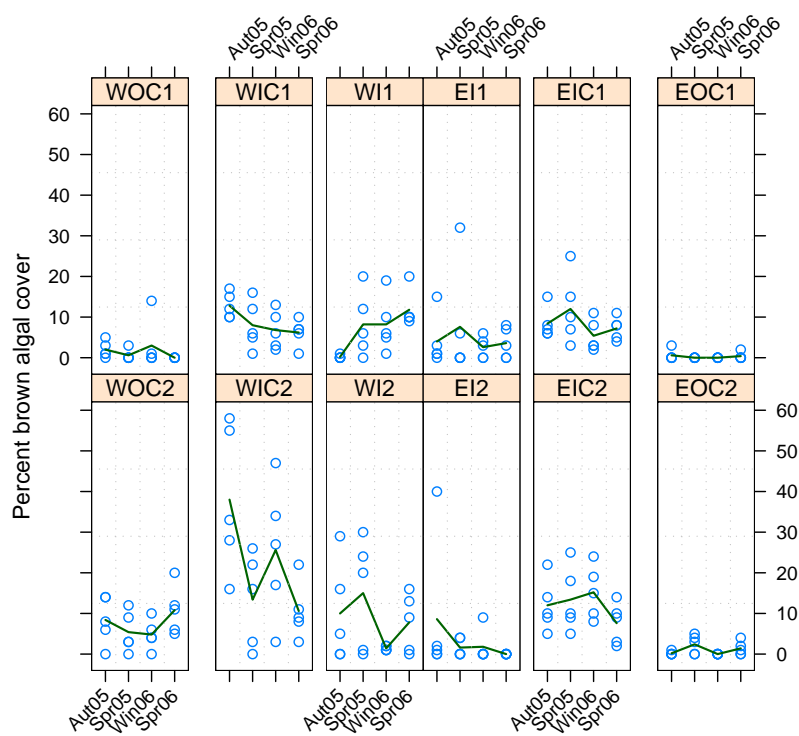


Figure 10: Percent cover by brown algae plotted as a function of sample date. Location abbreviations follow those of previous Aquenal reports. Each symbol denotes the value of a Site within each Location; the line in each panel connects the means on each sample date.

Aut05	Spr05	Win06	Spr06	LocType	
Impact	28.65	14.80	12.80	19.35	18.90
Inner Controls	38.15	26.70	27.55	38.45	32.71
Outer Controls	13.75	8.45	10.40	12.65	11.31
Date	26.850	16.650	16.917	23.483	

Table 10: Brown algal cover means

3.3 Fish

For square-root transformed total abundance, there were no differences between location types, but some strong differences between sample dates (Table 11, Figure 11), with Spring 2005 clearly showing increased abundances over the other dates (Figure 11). Species richness (square-root transformed) showed similar trends, which probably reflects the positive correlation between the number of species encountered and the number of fish collected. The notable “spike” in fish abundance (and hence species richness) in Spring 2005 is difficult to explain, but it suggests that fish abundance as measured by this technique may be quite variable through time.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Between Locations					
LocType	2	0.89	0.44	0.74	0.505
Inner	1	0.70	0.70	1.17	0.308
Outer	1	0.19	0.19	0.31	0.592
Residuals	9	5.42	0.60		
Within Locations					
Date	3	73.74	24.58	28.01	<0.001
SvS	1	54.72	54.72	62.36	<0.001
AvW	1	2.79	2.79	3.18	0.086
SvAW	1	16.22	16.22	18.48	<0.001
LocType×Date	6	3.03	0.51	0.58	0.746
Residuals	27	23.69	0.88		

Table 11: ANOVA of square-root transformed total numbers of fish. “LocType” is the type of Location, and the rows labelled “Inner” and “Outer” report the contrasts with the Impact Locations. “SvS” contrasts the two spring sample dates; “AvW” contrasts Autumn 2005 with Winter 2006; “SvAW” contrasts the average value of the spring dates with the average of the Autumn 2005 and Winter 2006 dates.

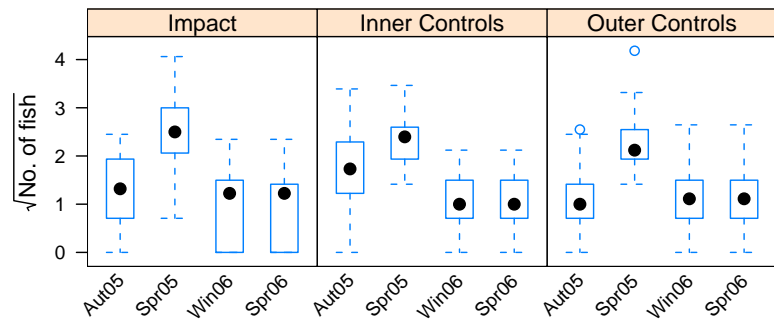


Figure 11: Boxplots of square-root transformed total numbers of fish plotted as a function of sample date for each type of Location. Large black dots denote the median.

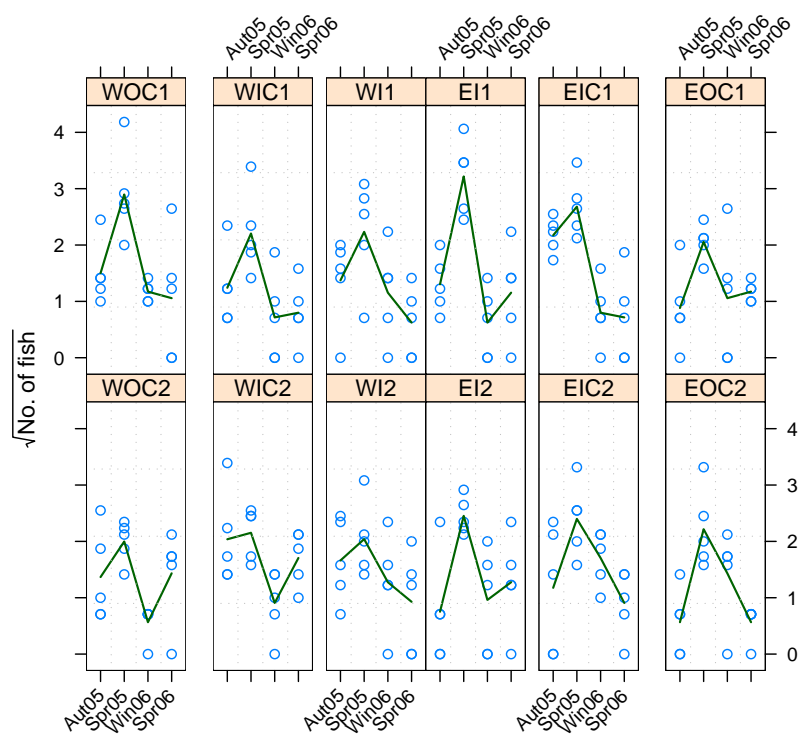


Figure 12: Square-root transformed total numbers of fish plotted as a function of sample date. Location abbreviations follow those of previous Aquenal reports. Each symbol denotes the value of a Site within each Location; the line in each panel connects the means on each sample date.

	Aut05	Spr05	Win06	Spr06	LocType
Impact	1.2723	2.4858	1.0037	0.9954	1.4393
Inner Controls	1.6570	2.3592	1.0318	1.0318	1.5200
Outer Controls	1.0790	2.2912	1.0572	1.0572	1.3711
Date	1.3361	2.3787	1.0309	1.0281	

Table 12: Square-root total fish abundance means

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Between Locations					
LocType	2	0.43	0.21	1.09	0.376
Inner	1	0.31	0.31	1.57	0.242
Outer	1	0.12	0.12	0.61	0.454
Residuals	9	1.76	0.20		
Within Locations					
Date	3	14.31	4.77	14.67	<0.001
SvS	1	7.51	7.51	23.10	<0.001
AvW	1	0.15	0.15	0.45	0.509
SvAW	1	6.66	6.66	20.48	<0.001
LocType×Date	6	0.80	0.13	0.41	0.866
Residuals	27	8.78	0.33		

Table 13: ANOVA of square-root transformed species richness of fish. “Loc-Type” is the type of Location, and the rows labelled “Inner” and “Outer” report the contrasts with the Impact Locations. “SvS” contrasts the two spring sample dates; “AvW” contrasts Autumn 2005 with Winter 2006; “SvAW” contrasts the average value of the spring dates with the average of the Autumn 2005 and Winter 2006 dates.

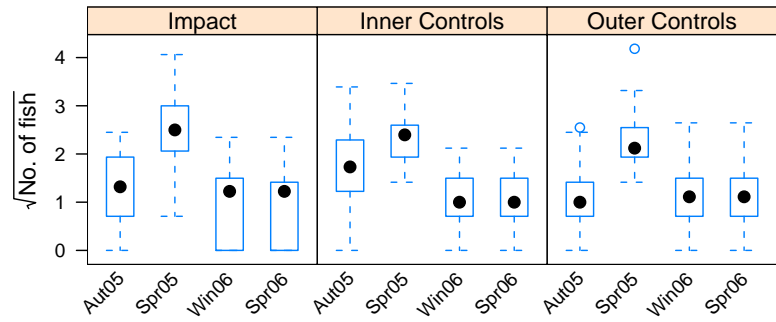


Figure 13: Boxplots of square-root transformed species richness of fish plotted as a function of sample date for each type of Location. Large black dots denote the median.

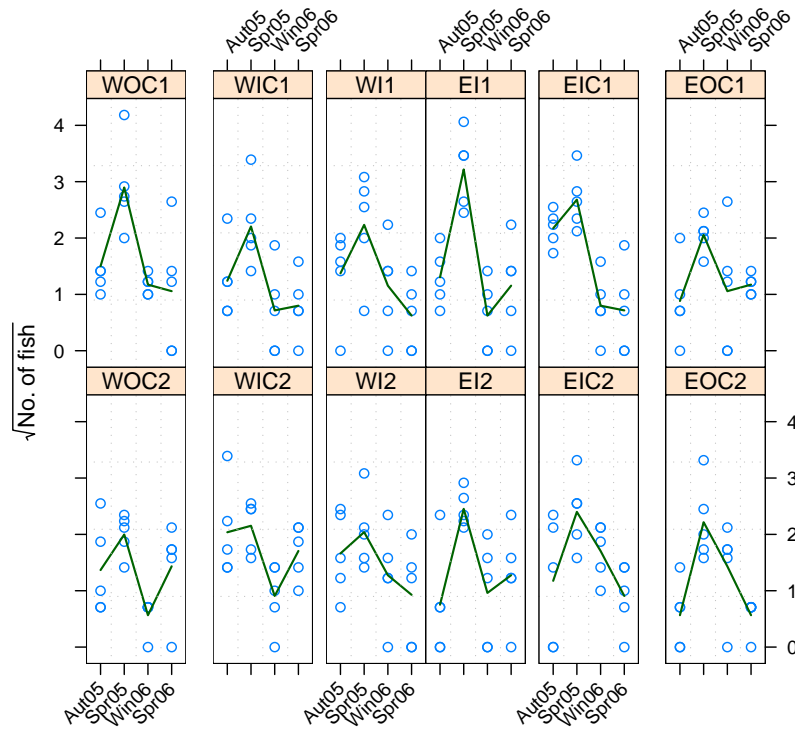


Figure 14: Square-root transformed species richness of fish plotted as a function of sample date. Location abbreviations follow those of previous Aquenal reports. Each symbol denotes the value of a Site within each Location; the line in each panel connects the means on each sample date.

	Aut05	Spr05	Win06	Spr06	LocType
Impact	0.9880	1.3584	0.8115	0.8555	1.0034
Inner Controls	0.8040	1.3552	0.7551	0.9049	0.9548
Outer Controls	0.8290	1.5527	0.8455	1.0050	1.0581
Date	0.8737	1.4221	0.8040	0.9218	

Table 14: Square-root fish species richness means

4 Discussion and conclusions

It is important to recall that the final MBACI analyses after commissioning of the outfall rest on detecting a change in the *pattern* of behaviour of the Impact Locations relative to the Controls, i.e. interaction terms in the design. Consequently, any spatial or temporal differences detected in these current analyses do not necessarily spell disaster. The most we can reasonably expect is that the Locations will be similar (but not identical) in their values on the response variables, and that the patterns shown over time are similar in all the Locations. Obviously, the longer the time period before commissioning, the stronger will be the tests that could later be carried out after commissioning. Conversely, very short pre-commissioning time-series will require us to rely more heavily on *ad hoc* arguments about the similarity among Locations.

Many of the response variables examined showed some modest spatial pattern, with the Inner Controls being less similar to the Impact Locations than (some of) the Outer Controls. This has also been detected in some of the multivariate analyses conducted on each sample date in previous Aquenal reports. The majority of the variables examined do not display egregiously asynchronous patterns amongst the locations through time, but neither do they display strong synchrony. This augurs well for the usefulness of an MBACI framework for the final monitoring programme, but the most problematic variables are those where the taxa concerned are currently in low abundance (e.g. red algae, fish abundance and species richness).

Before considering discarding these variables, two important points need to be made.

- Some rare taxa may *increase* in response to the start-up of the outfall (e.g. fish may be attracted to the effluent, some algae may benefit from nutrients), and these could be potentially powerful indicators. As ever, a comprehensive review of the relevant literature may yield some interesting cases of where this pattern has resulted from pulp mill discharges of this type.
- For the epibiota (i.e. algae), the improved sampling protocol, whereby only suitable reef habitat is sampled, will considerably improve the precision of estimates of algal cover. Similarly, it has become clear that the

current sampling design was also difficult to implement for infauna from soft bottoms in some Locations, and so the proposed changes to sampling locations may provide opportunities to select more comparable habitats among the sampling locations, which would further increase precision.

Finally, it should be noted that more sophisticated methods could be used to analyse the future sampling program. Linear and non-linear mixed modelling procedures now allow analysts to make more realistic assumptions about spatial and temporal autocorrelations and other structure in the data. While some critics argue that such procedures are only valid for “large” samples, the range of techniques available merits further investigation, and the data set assembled here should give analysts a good foundation upon which to evaluate competing methods.