Cooperative Research Centre for Coastal Zone Estuary and Waterway Management

Technical Report 10

Statistical analysis of the water quality of the Fitzroy River estuary (FE3)

Recommendations for improving current monitoring practices

Melissa Dobbie
Bronwyn Harch
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Statistical analysis of the water quality of the Fitzroy River estuary (FE3): recommendations for improving current monitoring practices

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Non-technical summary

The ambient water quality of the Fitzroy River has been monitored on an irregular basis below the barrage over the past twenty years. Since October 2000, the Queensland Environmental Protection Agency (QEPA) and the CRC for Coastal Zone Estuary and Waterway Management (Coastal CRC) have collaborated to undertake a more comprehensive monitoring program of water quality of the Fitzroy River from the barrage to the mouth. As well, Fitzroy River Water (Rockhampton City Council) supported fortnightly monitoring of six upper estuary sites for part of this period.

The main objective of this report was to provide recommendations on how the ambient monitoring of water quality below the barrage should proceed in light of our statistical analyses. Time and cost efficiency are two of the critical factors in improving the monitoring study and so should be streamlined. In particular, we were requested to make a recommendation on how often the monitoring sites should be sampled in future and on the extent of spatial coverage of the monitoring sites to ensure sufficient and credible inferences can be made.

Since monitoring commenced in 1980, 46 different physical and chemical water quality variables have been recorded, some more regularly than others, at various depths and at least one of 15 monitoring sites. Due to the lack of regularity with which some of this data has been recorded, we have only been able to focus on a subset of the data for our statistical analyses. Specifically, we have considered nine water quality variables, namely Dissolved Oxygen as a percentage of saturation relative to air (DO%sat), Electrical Conductivity (EC), Temperature (Temp), Turbidity (Turb), Total Nitrogen (TN), Ammonium (NH4), Nitrogen Oxides (NOX), Total Phosphorus (TP) and Filtered Reactive Phosphorus (FRP), recorded at a depth of 20cm at 13 sites between January 2000 and December 2002.

Based on the statistical analyses summarised in this report, we make the following recommendations for future ambient monitoring of the Fitzroy River “below the barrage”:

1. The number of sites can be reduced to **<u>seven</u>**: **three** in the upper estuary (say, above 45.2AMTD), **two** in the lower estuary (say, below 20AMTD), and **two** in the vicinity of the ox-bow (say, between 20AMTD and 33.8AMTD).
2. The sampling frequency remains **<u>monthly</u>**; there is not enough data or evidence to support a decrease or increase in the sampling frequency.
3. A pilot sampling survey is undertaken throughout the estuary where a minimum of **<u>five</u>** samples is collected at each site during each month. This will primarily enable calculation of a “true” variance for each site (i.e. within-site variability) during these times. This will also enable the optimal replication level to be determined for the variables of interest.
4. Relevant hydrological data, collected at the time of sampling, would enhance the analyses. These might include tidal data, such as flow of water and whether the tide is outgoing or incoming; and measurable flow inputs into the estuary such as that through the barrage.

Note: It is beyond the scope of this report to make recommendations in relation to specific water quality parameters included in the monitoring program.

Acknowledgments

We would like to acknowledge the contributions of a number of organisations that have provided or collated data for our statistical analyses and/or provided feedback on proposed tasks within the project. These agencies (in alphabetical order) include:

- the Cooperative Research Centre for Coastal Zone Estuary and Waterway Management for collection, collation and provision of the data from the various agencies in the region
- the Fitzroy Basin Association for feedback on proposed tasks within the project
- Fitzroy River Water for provision of bimonthly water quality monitoring data throughout upper reaches of river estuary (near Rockhampton)
- the Queensland Environmental Protection Agency for monthly water quality monitoring data throughout the river estuary
- the Queensland Department of Natural Resources & Mines for provision of flow data.

Thanks also to Bob Noble, CRC Coastal Zone Estuary and Waterway Management, and Chris Marshall, Queensland Department of Natural Resources and Mines, who provided constructive comments, which helped to improve the report.

1 Introduction

1.1 Background to study area

The Fitzroy catchment is the second largest in Australia at nearly 150,000km^2. Industry-wise, it is dominated by agriculture (grazing, dryland cropping, irrigated cotton and horticulture) and by mining (coal production of 100 million tonnes/year, magnesite, nickel and historically gold and silver).

The Fitzroy River estuary is now 60 km in length after being approximately halved with the construction of a barrage in Rockhampton in 1970. The river discharges into Keppel Bay, with the mouth to the east of the northern end of Curtis Island. Keppel Bay supports a major scallop, prawn and fish industry, as well as being a leisure and tourism hub. The estuary has been described as a pipe delivering fresh water to the bay with river discharge predominantly directed northward past the tourist centres of the Capricorn Coast.

1.2 Objectives

There is a deficiency in scientific knowledge and understanding of the estuary and coastal zone, and consequently, minimal scientific input into management and planning decisions (http://www.coastal.crc.org.au/fitzroy/index.html, 31 July 2003). Hence one of the aims of undertaking a statistical analysis of the historical water quality data is to develop a more efficient spatio-temporal design for monitoring water quality of the Fitzroy River estuary.

The main objective of this report is to provide recommendations on how the ambient monitoring of water quality below the barrage should proceed in light of our statistical analyses. Time and cost efficiency are two of the critical factors in improving the monitoring study and so should be streamlined. In particular, we are requested to make a recommendation on how often the monitoring sites should be sampled in future and on the extent of spatial coverage of the monitoring sites to ensure sufficient and credible inferences can be made.

1.3 Computing details

All data were collated in Microsoft Excel^{TM}, and were explored, analysed and graphed in the statistical software package S-PLUS^{TM} 6.1 (Insightful Corporation^{TM}).

1.4 Report outline

Numerous records of water quality data were provided but only a subset was selected for further analysis. A description of this subsetted data is provided in Section 2. Also described in Section 2 are other data sources of potential interest, including tidal logger data, flow data and sewage treatment plant (STP) input information, which may impact on conclusions reached through our analyses, if taken into account. In Section 3, we outline various univariate and multivariate approaches to analysing the data, and then in Section 4, summarise and provide some initial statistical interpretations of the key results of these analyses. Conclusions, recommendations and future directions follow in Sections 5, 6 and 7, respectively. There are five appendices of supporting tables and figures, which have been referenced in the report.

2 Data description

A description of the water quality data and the sampling intensity and locations is presented in Section 2.1. Additional data of potential relevance for making inferences about water quality are described in Section 2.2.

2.1 QEPA historical water quality data

The ambient water quality of the Fitzroy River has been monitored on an irregular basis below the barrage over the past twenty years. Since October 2000, the Queensland Environmental Protection Agency (QEPA) and the CRC for Coastal Zone Estuary and Waterway Management (Coastal CRC) have collaborated to undertake a more comprehensive monitoring program of water quality of the Fitzroy River from the barrage to the mouth.

Since monitoring commenced in 1980, 46 different physical and chemical water quality variables have been recorded, some more regularly than others, at various depths and at at least one of 15 monitoring sites. Due to the lack of regularity with which some of this data has been recorded, we will only focus on a subset of the data for our analyses. This subset was identified via consultation with Coastal CRC staff based at Rockhampton.

Specifically, we will only consider nine water quality variables, namely Dissolved Oxygen as a percentage of saturation relative to air (DO%sat), Electrical Conductivity (EC), Temperature (Temp), Turbidity (Turb), Total Nitrogen (TN), Ammonium (NH4), Nitrogen Oxides (NOX), Total Phosphorus (TP) and Filtered Reactive Phosphorus (FRP), recorded at a depth of 20 cm at 13 sites between January 2000 and December 2002. This data has been made available on CD; see Appendix 1. We now briefly provide some background on, and details of, various aspects of this subsetted data.

2.1.1 Location of monitoring sites

The 13 monitoring sites located below the barrage are plotted in Figure 1 and are identified, and hereafter labelled, by their Adopted Middle Thread Distance (AMTD), namely the distance along the river from the middle of the mouth of the river to the middle of the river at that location. For reference, the barrage is located at 60AMTD.

In 1991, a large rainfall event caused the river to permanently cut through the 10km ox-bow between Sites 20 and 33.8. The main flow path is now across the ox-bow, which has more or less isolated Site 28.1. The variables recorded at this site after 1991 may be atypical and hence, any inferences concerning Site 28.1 need to be made with caution.

The upper five sites, 50.2, 52.6, 55.1, 57.3 and 59.6, are specifically located within 10 km of the barrage, in order to monitor known licensed outfalls into the river. Further details about these outfalls are provided in Section 2.2.3.

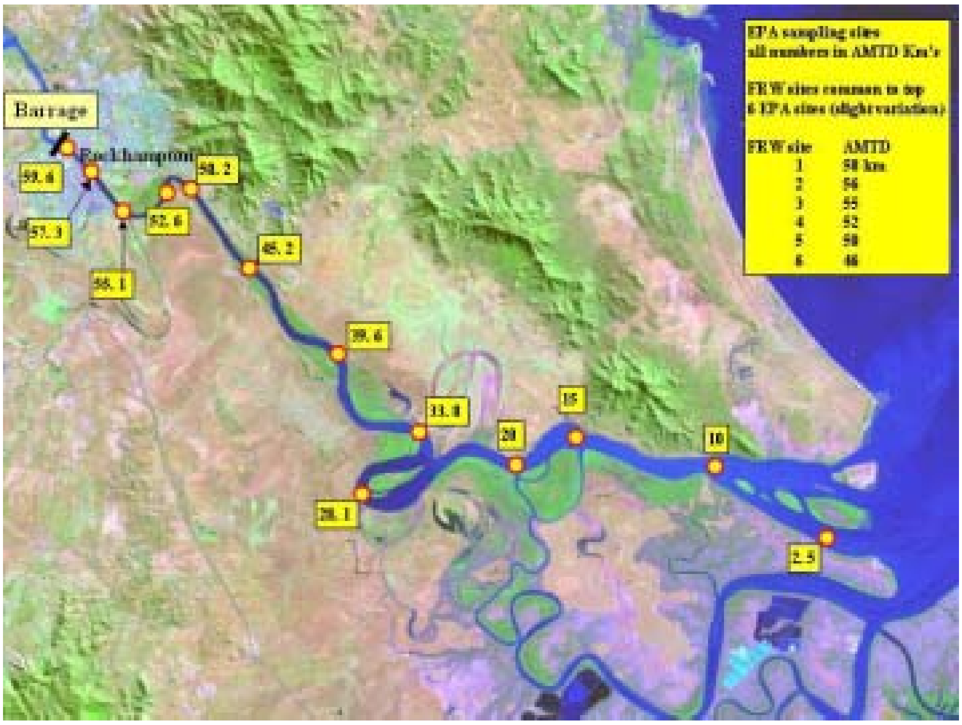

Figure 1: Location of the QEPA monitoring sites below the barrage on the Fitzroy River (courtesy of Coastal CRC)

2.1.2 Sampling details

The chemical water quality variables were obtained from grab samples (one per variable) taken 20 cm below the water surface, but were, at times, also recorded at other depths within the profile (i.e. depending on the depth of the river at that site). The physical water quality variables were obtained from samples grabbed at various depths within the profile. In general, samples were taken from the deeper part of the river, as the most flow occurred at this spot. Note that the sampling location wasn't necessarily the centre of the river.

Sampling runs started at the mouth of the river in the morning, mostly on an outgoing tide (just after the tide had turned) and continued upstream. The aim was to complete all sampling on the same tidal motion, however there were occasions when the tide had turned by the end of a run so that the runs were completed on an incoming tide. Obviously the closer a site is located to the mouth of the river, the greater the impact of the tides on the quality of water at that site (in relation to resuspension), so the timing of incoming/outgoing tides is potentially of little impact on the water quality at upstream sites. The lower three sites, 2.5, 10 and 15, being closest to the mouth of the river, are radically influenced by tides, which range from 0.3m to 4m on average, creating high velocity tidal flows. However, sampling was usually completed within two hours at these sites to avoid such issues. There was no adjustment made for tides in the provided data.

2.1.3 Recorded data

At all sites and on all occasions, an accurate depth measurement was recorded along with the date and time at which the sample was obtained. Site, depth, month and year are the independent variables of interest to us, that is, those we generally assume to be measured and recorded without error.

Dissolved Oxygen (%saturation) is the percentage of Dissolved Oxygen (mg/L) relative to air. Electrical Conductivity is measured in dS/m (decisiemens per metre) and Temperature is recorded in degrees Celsius. Note that a weighted combination of Electrical Conductivity and Temperature can be used as a surrogate measure for salinity. A direct measurement of Turbidity was determined in-situ and is recorded in nephelometric turbidity units (ntu). The five Nitrogen and Phosphorus variables were all measured in mg/L.

2.2 Additional data

2.2.1 Fitzroy River Water (FRW) water quality data

Since September 2001, Fitzroy River Water (FRW) have undertaken sampling at six sites below the barrage on the Fitzroy River, which more or less correspond to the QEPA six monitoring sites directly below the barrage and focus on monitoring impacts from the licensed outfalls. Sampling frequency is fortnightly, usually on a Monday, so the timing was not based on tides at all. More than 20 water quality variables have been recorded. It was beyond the limited scope of this report to incorporate these data into our analyses.

2.2.2 Gauging station flow data

Two gauging stations, Wattlebank and The Gap, are located about 80 km upstream of the barrage and each record total flow in ML/day over a 24-hour period. There is an approximate 1.5-day lag for flow recorded at the gauging stations to reach the barrage, and the flow data have been adjusted accordingly. In addition, a gauged flow record is measured with an accuracy of approximately ±10%.

Whilst flow would have an impact on the quality of the water in a natural system with no barriers, the barrage acts to separate fresh upstream waters from the downstream marine waters during low- or no-flow conditions. However, the barrage gates can be manually opened to allow flows into the estuary. For flow volumes greater than 1000 ML/day, there are considerable changes in conditions in the estuary. In particular, after substantial flows (small floods) occur, the system below the barrage will be mostly fresh water with the marine conditions returning over a period of four to six months on average. Details of when the barrage gates have been manually opened are recorded but were unavailable at the time of our analysis.

During high flow events, large amounts of fresh water and suspended sediments are transported into the marine system with highly turbid conditions remaining for many months. During the subsequent low flow periods, suspended sediments settle out and conditions return to a less turbid state with algal blooms decreasing water clarity in the upper estuary towards spring/summer. The lower estuary is constantly turbid due to high tidal velocities and resuspension of fine sediments.

The median monthly flows (in ML) above the barrage, which were calculated between January 2000 and July 2002 (latest data available), are presented in Table 1. These may be useful in helping to interpret our clustering of water quality measurements over time (see Section 4.2.1). We have also presented the standard error of flow for each month in Table 2.

Table 1: Median monthly flows (in ML) above the barrage

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	1813.6	2017.4	2073.8	3718.3	11139.1	1661.5	662.4	236.3	101.7	253.4	26741.1	3555.3
2001	4224.2	6136.3	3384.3	599.3	223.9	72.5	92.2	178.6	219.5	190.0	172.9	178.2
2002	3944.6	1830.2	820.7	146.6	200.0	1841.3	389.3	NA	NA	NA	NA	NA

NA – data not available for this month

Table 2: Standard error of flow (in ML) above the barrage

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	2285.9	20321.0	15691.7	4701.4	16460.7	1129.7	359.2	69.9	65.7	17.2	83728.3	13322.6
2001	15616.4	23802.8	3172.2	786.0	59.1	40.4	70.7	37.0	17.0	38.0	63.0	26.1
2002	15275.9	3846.2	686.1	209.8	67.7	2944.2	91.6	NA	NA	NA	NA	NA

NA – data not available for this month

2.2.3 Additional input into below barrage system

Three sewage treatment plants (STPs) are located downstream of the barrage and contribute flow input on a continual basis into the river system. They are located just below Site 59.6 (West Rocky STP), at 56.5AMTD (North Rocky STP), and at 55AMTD (South Rocky STP). All STPs perform secondary treatment of the effluent and add chlorine before releasing into the river. Altogether, they contribute an average of 16 ML/day to the river; 10 ML/day is typically output from the North Rocky STP alone. Outfall from STPs usually affects NH4 levels, and thus affects TN.

In addition, a fish ladder is located on the barrage i.e. at 60AMTD, and flow output from this contributes about 17 ML/day to the system. The fish ladder was installed in the 1980s, however it is sometimes blocked up with weed and hence not operable.

The STP effluent of 16 ML/day will affect salinity levels and nutrient levels in the upper estuary (if the system is in a marine state), whereas the fish ladder flow will mainly affect only the salinity levels. Combined, they have little effect on the lower estuary conditions and hence GBR lagoon.

2.2.4 Tidal logger data

Tides will likely play an important role in the quality of the river below the barrage, not only because they ensure the whole system is flowing, but also because monitoring sites were sampled starting at the mouth of the river and heading upstream to the barrage, which took approximately the period of a tide, i.e. about 6 hours. There is a tidal logger located at Site 50.2, which basically indicates whether a tide is rising or falling, however these data were not available at the time of analysis. We are therefore forced to ignore any possible tidal effects.

3 Approaches to statistical analysis

To meet our objectives (Section 1.2), a combination of univariate and multivariate exploratory tools were employed, which are now briefly outlined.

3.1 Univariate exploration

Quantitative summaries of each water quality variable were produced, including the number of observations (both missing and in total), the minimum, maximum, quartiles and the mean. Tabulations and cross-tabulations of categorical variables including year, month and site were also produced. These allowed us to observe in detail the irregularity with which the data had been collected and helped to identify possible anomalies in the data. The tabulations also allowed us to check the validity of uncertainty associated with some of the statistics calculated, by observing the number of observations contributing to the calculations.

We produced boxplots for each water quality variable, for all data and also stratified according to the design variables, namely site, month and year. Boxplots are graphical summaries which enable a quick assessment of the distribution shape of water quality, the degree of variability within the data, the median or middle value, the presence of anomalies in the data, the presence of any patterns across categories for a water quality variable, and possible interactions between covariates. See the boxed text for a brief explanation of how to interpret a boxplot.

Brief Explanation of a Boxplot (or box-and-whisker plot):

The box defines the 25th and 75th percentiles, the line across the box denotes the 50th percentile (or median), the lines (or whiskers) drawn from the 25th and 75th percentiles indicate the smallest observations within 1.5 times the inter-quartile range or IQR (difference between the 75th and 25th percentile) and observations outside the lower and upper fences indicate outlying observations. For further information about boxplots, see Cleveland (1985, pp 129-134).

To ascertain whether there is any correlation between sites for each water quality variable, we calculated the Spearman's rank correlation coefficient. This method offers a nonparametric form of the well-known Pearson's product moment correlation coefficient and is useful for exploring the degree of linear association between water quality measurements at two sites.

3.2 Multivariate exploration

The multivariate pattern analysis techniques used include those that are generally known as hypothesis generating or exploratory statistical techniques. These techniques aim to display and summarise a set of multivariate measurements and thus provide a basis for pattern interpretation.

In this context, pattern analysis methods are able to quantify the degree of similarity among samples, here sites or sampling times, when given a multivariate set of water quality data. This information may then be used to inform any future spatio-temporal sampling strategies. The main advantage of using pattern analysis on water quality data is to examine similarities between sites and sampling times simultaneously.

Pattern analysis can be divided into two broad approaches, namely ordination and clustering.

3.2.1 Ordination

Ordination can be used to find any structure in a multivariate dataset by arranging the levels of a predictor variable of interest in a low-dimensional space in relation to underlying gradients, such that a visual representation of the variable is obtained. Similarities between levels of the variable are reflected by inter-point distances between the levels, when they are represented by a set of co-ordinates in space (Digby and Kempton, 1987). Consequently, the distance between levels, in the plot produced, represents the degree of similarity or dissimilarity between levels as measured by the original response variable. Thus, the main aim of ordination is to display the levels of the predictor variable in a reduced dimensional space with minimal loss of information and to provide an indication of whether *true* groups exist.

Ordination techniques were employed in our analysis to visualise what structure exists between sites and between sampling times for each of the nine water quality variables. Principal Component Analysis (PCA), based on the correlation matrix, is commonly employed for revealing structure in such data. PCA was used here because of its usefulness for jointly displaying the similarity amongst both the sites and the sampling times on a single graphical representation, known as a biplot (Gabriel, 1971).

Biplots are used to graphically display the relationships between sites, as indicated by their inter-individual distance, and between the sampling times, as indicated by their covariances and correlations (Gabriel, 1971). The relationships between sites and between times are displayed as point-vector plots, with black labelling representing time and red-labelled vectors representing sites. The directional vectors indicate increasing values for the descriptors. The point the descriptor vectors radiate from represents the sample average for each of the descriptors. The angles between the vectors reflect the correlation structure among the descriptors. By drawing a perpendicular line from the time points to the descriptor vectors, the descriptor measurements for the times can be compared to the sample average. The distance of the red points from the origin indicates increasing influence for that site. Missing values were replaced by the mean of the non-missing entries.

For a more detailed explanation of ordination techniques, refer to Digby and Kempton (1987).

3.2.2 Clustering

Clustering summarises the structure of a community by assigning the levels of a variable of interest to groups, with the main objective of grouping levels as similar as possible and having the groups as dissimilar as possible (Gauch, 1982; Digby and Kempton, 1987). Using such techniques, we aim to summarise the water quality data by assigning sites or sampling times to groups. These techniques require formation of similarity or dissimilarity matrices. (Note that there are algebraic expressions to transform similarity matrices to dissimilarity matrices, and vice versa). We used Euclidean distance to form similarity matrices across the water quality variables for each site-to-site and time-to-time comparison.

Sites/times were then grouped through agglomerative hierarchical cluster analysis. Agglomerative hierarchical clustering starts with each sample being successively grouped with similar sites/times, with groups forming a hierarchical system of grouping until all sites/times are joined into a single cluster. The specific clustering algorithm routine employed was average linkage. Missing values were accommodated through this algorithm.

A graphical representation of the hierarchical clustering solutions for sites/times is provided in a tree-like plot known as a dendrogram. The dendrogram allows visualisation of the successive groupings of the sites/times through to a single cluster. The vertical axis of the dendrogram (labelled as ‘Height’) represents the increasing level of dissimilarity amongst the sites/times.

Determining the appropriate number of clusters represented by the data is a subjective decision. It may be based on the relative distance amongst the successive groups in the dendrogram, as well as wanting to represent the sites/times with a relatively small number of clusters.

Further details about cluster analysis are provided in Digby & Kempton (1987).

4 Results

In Section 4.1, we summarise both visual and quantitative univariate exploratory analyses. A summary of the site and sampling time similarities for each water quality variable is presented in Section 4.2.

4.1 Univariate explorations

A relatively low DO%sat value, a high NH4 value, and the 12 unusually large TN values recorded on 8 October 2002, were all omitted from subsequent analyses after some investigation. A small number of repeat samples (i.e. same depth, time, water quality variable) were also removed to avoid false sample size issues.

4.1.1 Summaries – quantitative and tabular

Table 3 provides details of quantitative summaries of each water quality variable, namely the minimum, maximum, median (middle value of the ordered data), mean, the first and third quartiles, Q1 and Q3 respectively (which are the 25th and 75th percentile values of the ordered data), the total number of observations recorded, the number of missing observations, and the number of sites at which the variable was recorded.

Table 3: Quantitative summaries of each water quality variable

Summary	*DO%sat (%)*	*EC (dS/m)*	*Temp (ºC)*	*Turb (ntu)*	*TN (mg/L)*	*NH4 (mg/L)*	*NOX (mg/L)*	*TP (mg/L)*	*FRP (mg/L)*
Minimum	64.9	0.13	17.6	1	0.1	0.002	0.003	0.007	0.004
Q1	83.3	9.7	21.7	15	0.4	0.004	0.11	0.078	0.028
Median	91.8	37.4	24.7	42	0.6	0.009	0.2	0.15	0.07
Mean	95.1	31.2	24.8	113.4	0.6	0.045	0.252	0.18	0.106
Q3	97.9	48.8	27.3	141.7	0.9	0.03	0.37	0.248	0.18
Maximum	200	56.3	31.6	956.6	1.6	0.52	1	0.67	0.4
Total obs	278	279	279	279	314	325	326	326	234
# Missing	0	0	0	0	0	39	9	0	4
# sites	13	13	13	13	12	12	12	12	12

Comparing means and medians, we see that the means of Turbidity (Turb) and Ammonium (NH4) are substantially greater than their medians. The distributions of the data for these variables are highly skewed to the right. Consequently, a logarithmic transformation (to base *e*) helped “normalise” the distribution of these values. All further inferences of these variables are based on their logarithms.

There were a number of missing observations for three of the water quality variables. Twelve percent of Ammonium (NH4) values were missing, and much smaller percentages of Nitrogen Oxides (NOX) and Filtered Reactive Phosphorus (FRP) values were missing. The missing values of FRP were all recorded in October 2002, implying that these were most likely not missing at random. Likewise, the missing values for the other two variables do not appear to be missing at random. Nonetheless, we will assume that any missing values are missing completely at random which means that the corresponding observations are ignorable and therefore will be excluded from our subsequent analyses, if necessary.

Tabulations of the number of observations in each combination of the levels of the spatial-temporal variables (i.e. site, year and month) are presented as one of six different groupings of the water quality variables in Appendix 2.

From the tabulations, we observe the irregular nature with which sampling occurred spatially and temporally in the estuary. For example, we observed that in the year 2000, DO%sat, EC, Temp and Turb were only recorded in March, October, November and December; TN, NH4, NOX and TP were only recorded at a maximum of two sites in January – September but were recorded at all sites in October, November and December; and that FRP was only recorded in November at 10 sites (not at 2.5, 15 or 59.6). In fact, DO%sat, EC, Temp and Turb were only recorded in March in the year 2000 and not in March in the following two years. This means that any inferences that we make about the level of these water quality variables in March (i.e. a month or season effect) are only based on one observation recorded at each site. We're certainly not confident about such inferences. Likewise, these same four variables were only recorded in June in the year 2001, and not in June in the other two years of interest, so we need to be careful when making inferences about the level of these variables in June.

FRP was only recorded in January – April in the year 2002 (and not the other two years) and in August in 2001 (and not the other two years), so inferences for these months and years need to take this into account. Inferences about site 59.6 are based on the recordings of only DO%sat, EC, Temp and Turb.

For all variables, the number of observations recorded in 2000 was much smaller compared to those recorded in the other two years and the majority of these were recorded only in the last quarter of 2000, so inferences made about year effects need to take this into account.

4.1.2 Boxplots

Each of Figure 2-10 displays four sets of boxplots for each of the nine water quality variables. See Section 3.1 for information on how to interpret boxplots.

From Figure 2(a) we observe that quite a number of DO%sat observations are larger than the boxplot's upper fence. There doesn't appear to be a year or site effect (Figure 2b and Figure 2d), but there is possibly a seasonal effect (Figure 2c). The median DO%sat is relatively higher in May, June and September relative to the other months, but the inter-quartile range (IQR), which is a surrogate for variability, is also wider for these three months.

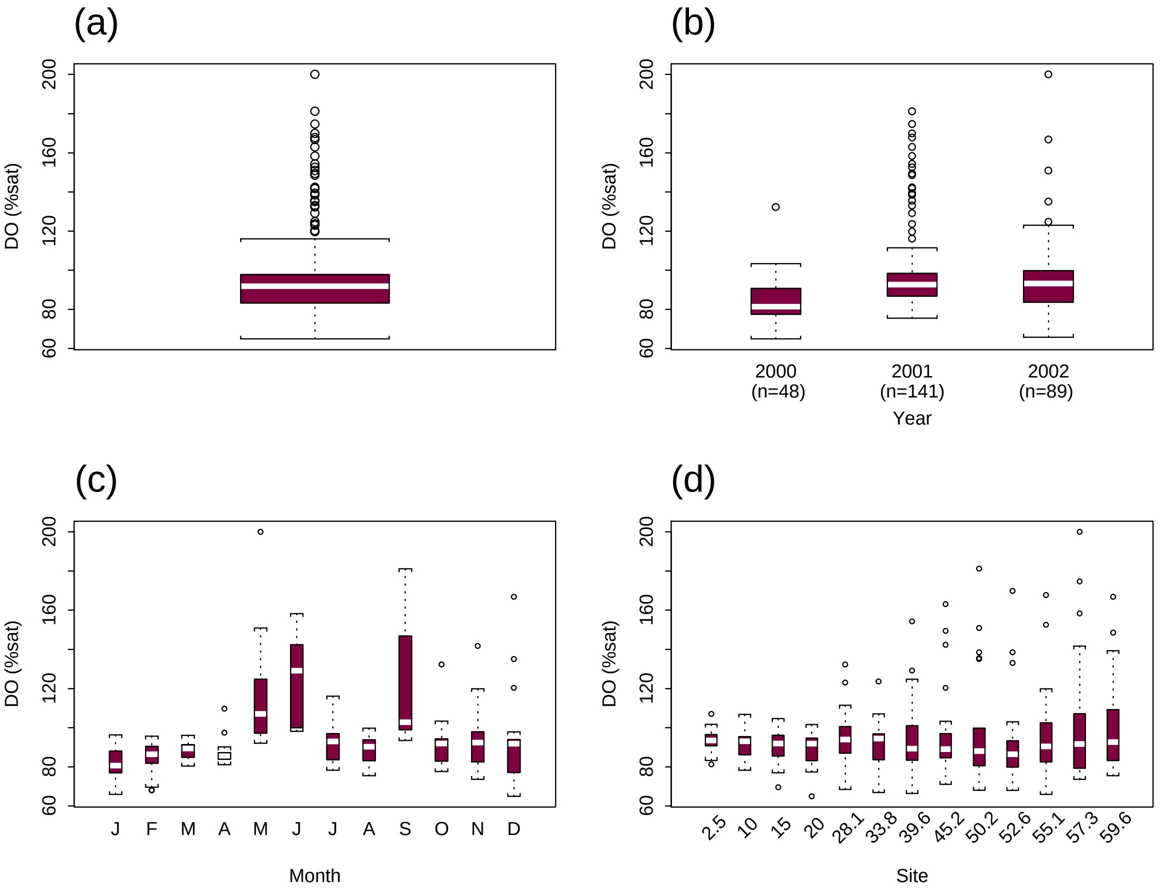

Figure 2: Boxplots of Dissolved Oxygen (%saturation) for (a) all data, (b) years, (c) months, and (d) sites

From Figure 3(a), we observe that the distribution of EC appears to be slightly skewed to the upper values, however there are no observations that fall below or above the fences of the boxplots (i.e. no obvious anomalous observations). There appears to be a year effect, with the median EC in 2000 being much lower than that for the other two years (see Figure 3b). However, the IQR is marginally wider in 2000 and there is certainly an overlap of the IQRs and the whiskers for all boxplots, so this effect is likely to be insignificant and is possibly an artefact of the number of observations recorded in each year.

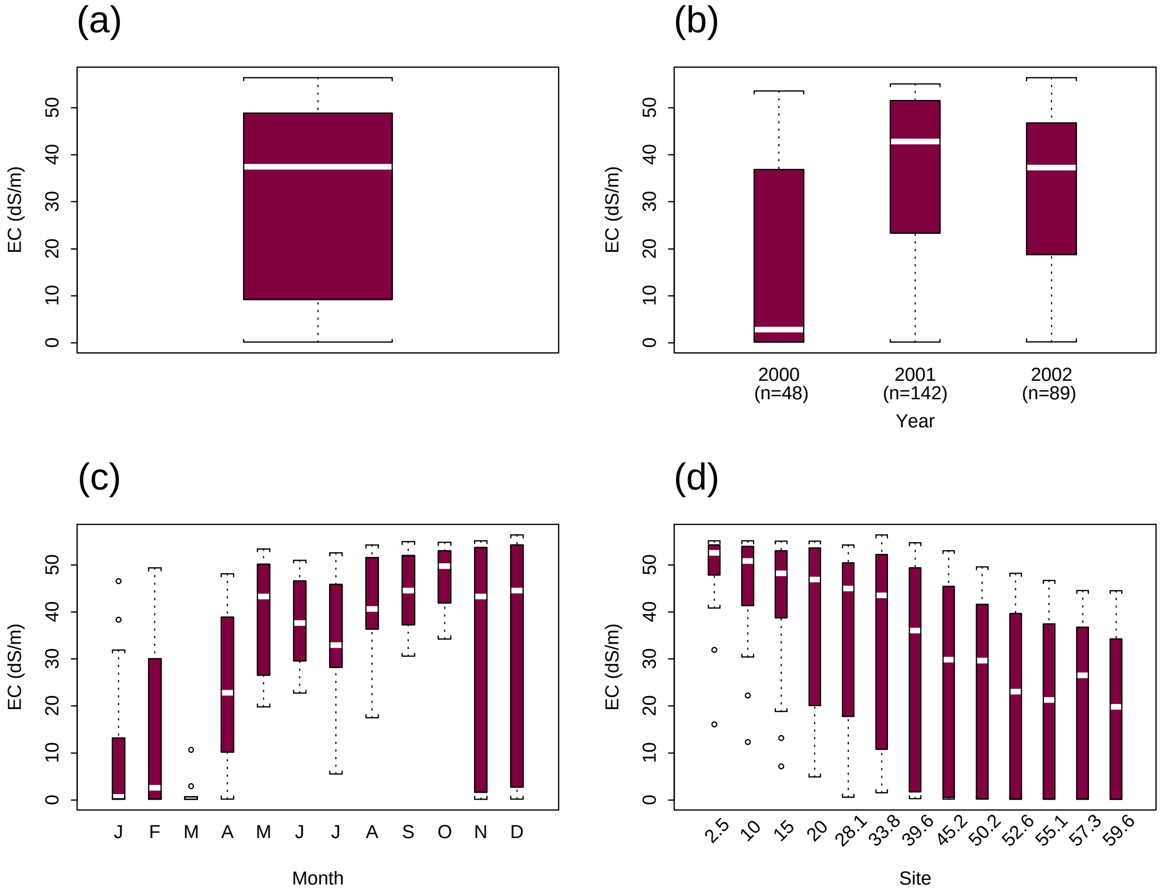

Figure 3: Boxplots of Electrical Conductivity (dS/m) for (a) all data, (b) years, (c) months, and (d) sites

Figure 3(c) indicates that there is likely to be a seasonal effect on EC, with roughly increasing median EC during the year. There are a couple of interesting aspects of these boxplots to note: the IQRs for November and December are huge, relative to the other months, indicating how variable the EC measurements are in those two months, and secondly, seeing as time is continuous, it seems very unusual that the distribution of EC in December compared to January should be so different. One explanation is that rainfall was highest in January in these three years, and thus introduced much freshwater to the estuary at this time. There are no obvious anomalous observations highlighted in the plot.

There is certainly a site effect on EC (Figure 3d), namely EC tends to increase the closer the site is to the mouth of the river. This is not surprising in an estuarine system. The median EC value increases from about 20 dS/m just below the barrage to about 52 dS/m at the mouth of the river, whilst the IQR or variability roughly decreases with distance from the barrage.

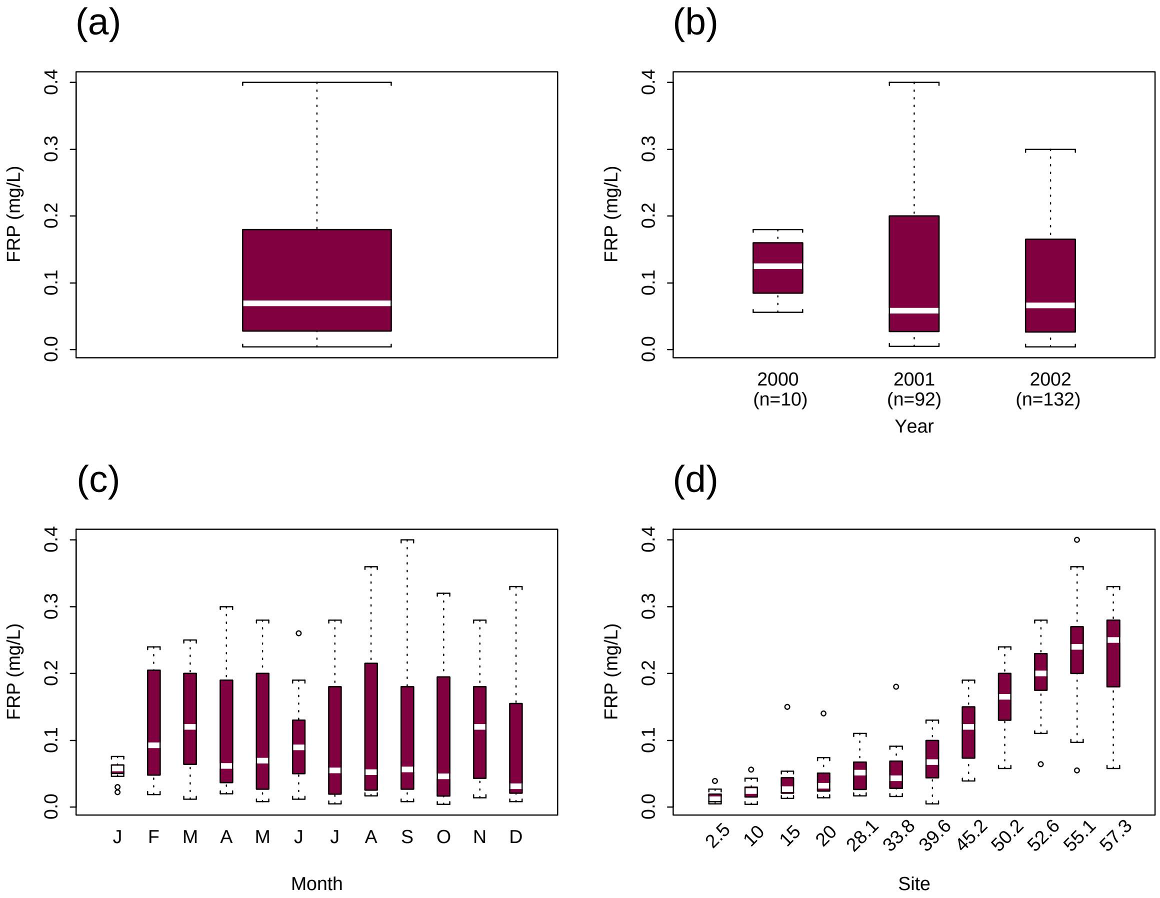

Figure 4: Boxplots of Filtered Reactive Phosphorus (mg/L) for (a) all data, (b) years, (c) months, and (d) sites

The distribution of FRP values is skewed to the larger values, but there does not appear to be any anomalous observations (Figure 4a). There is no apparent year effect (Figure 4b), nor seasonal effect (Figure 4c), taking into account the sparseness of data recorded in 2000 and in January – April over the three years. However, there does appear to be a site effect (Figure 4d), with median FRP decreasing from 0.25 mg/L from within a few kilometres of the barrage, to close to 0 near the mouth of the river. The corresponding IQR also decreases with increasing distance from the barrage.

From Figure 5(a) we see that the distribution of the logarithm of NH4 is relatively Normally distributed and that no apparent outlying observations have been identified. There is no apparent year effect (Figure 5b), but there are potentially seasonal and site effects; see Figure 5(c) and Figure 5(d) respectively. The seasonal effect arises due to NH4 being clearly highest in July and August and lowest in March – May. Variability is also highest in the winter months and smallest in summer and autumn. NH4 is clearly higher (and more variable) at the upstream sites more than 45 km from the river mouth and lowest at the river mouth. The median NH4 level rises steadily the further upstream the site is, with the median NH4 level at site 28.1 seeming relatively high. There is also an apparent “threshold” between sites 39.6 and 45.2, where median NH4 values are obviously different. This features in site boxplots for other water quality variables.

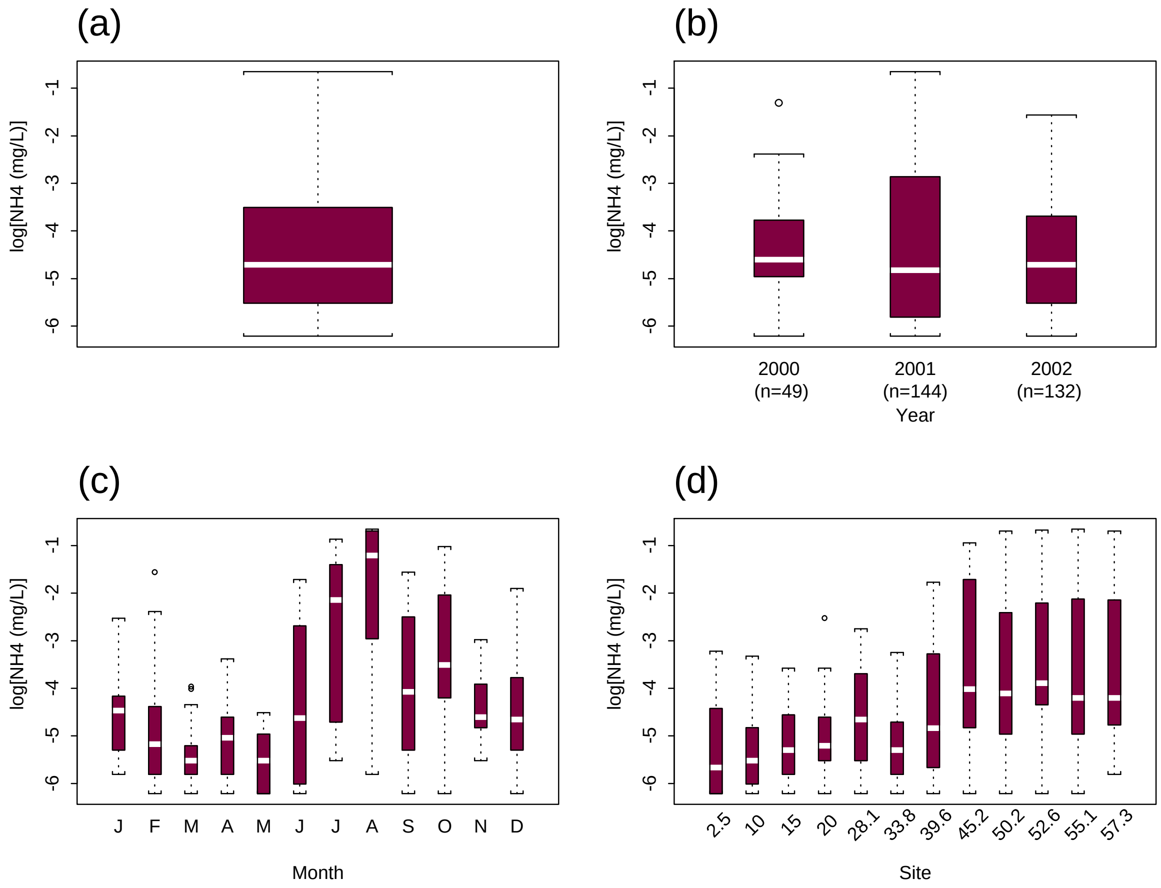

Figure 5: Boxplots of the logarithm of Ammonium (mg/L) for (a) all data, (b) years, (c) months, and (d) sites

The distribution of NOX values is skewed to the upper values (Figure 6a). We observe that the median NOX (and its variability) is lower in 2001 relative to 2000 and 2002, but this does not appear to be a significant year effect (Figure 6b). From Figure 6(c), there appears to be some seasonal effect: NOX is lowest and least variable in April – June and greatest and most variable in September – November. Also, the median NOX is lower than expected in December, compared to the November and January median values. NOX values steadily increase the further upstream the sampling is undertaken; see Figure 6(d). The variability also increases with distance from the mouth of the river. Sites more than 45 km from the mouth of the river have higher NOX levels than at sites further downstream. The "threshold" observed with NH4 (Figure 5d) is also apparent in NOX between sites 39.6 and 45.2.

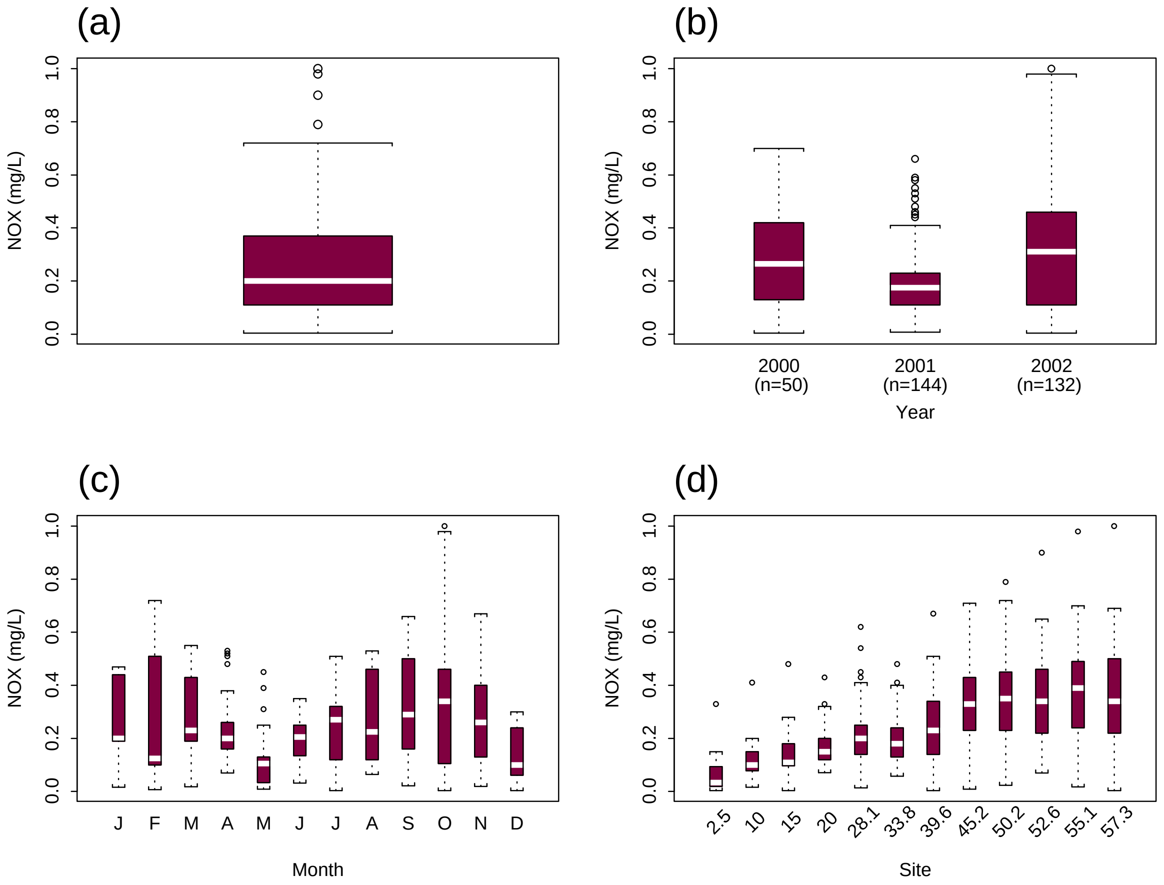

Figure 6: Boxplots of Nitrogen Oxides (mg/L) for (a) all data, (b) years, (c) months, and (d) sites

According to Figure 7(a), Temperature values appear to be Normally distributed. The median Temperatures for each of the three years do not appear to be significantly different but we note that the IQRs and ranges of Temperatures increased over the three years (see Figure 7b). As expected, there is a clear seasonal effect on Temperature (Figure 7c), with highest Temperatures occurring in January and February and lowest in July. The variability (IQR and magnitude of range) was highest in November and February. There were no apparent site differences in temperature, according to the median values, IQR or range of the data.

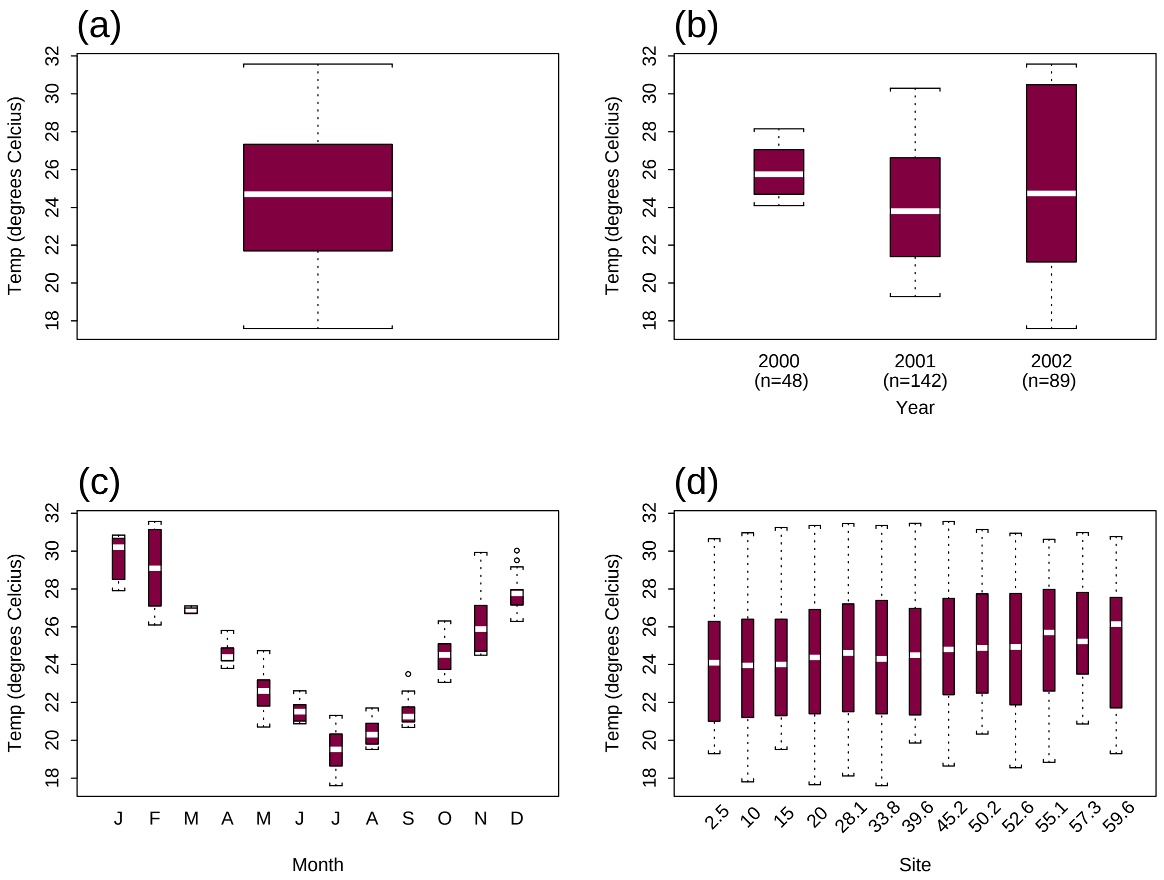

Figure 7: Boxplots of Temperature (ºC) for (a) all data, (b) years, (c) months, and (d) sites

Figure 8(a) shows the distribution of TN values. There is possibly a weak year effect in TN with median TN decreasing over the three years (Figure 8b). There is also an apparent marginal seasonal trend with median TN generally decreasing from January to June and then generally increasing over the rest of the year (Figure 8c). TN was least variable between February and June. Once again, the median December TN level was considerably lower than that for November and for January. Perhaps this is due to a reduced output from STPs over the Christmas period. There is certainly a site effect (Figure 8d), with TN highest just downstream of the barrage, both in terms of its middle value and its range. There is a clear difference in the median TN level between site 45.2 and site 39.6. Figure 8(d) also highlights a number of potentially anomalous observations occurring through the estuary.

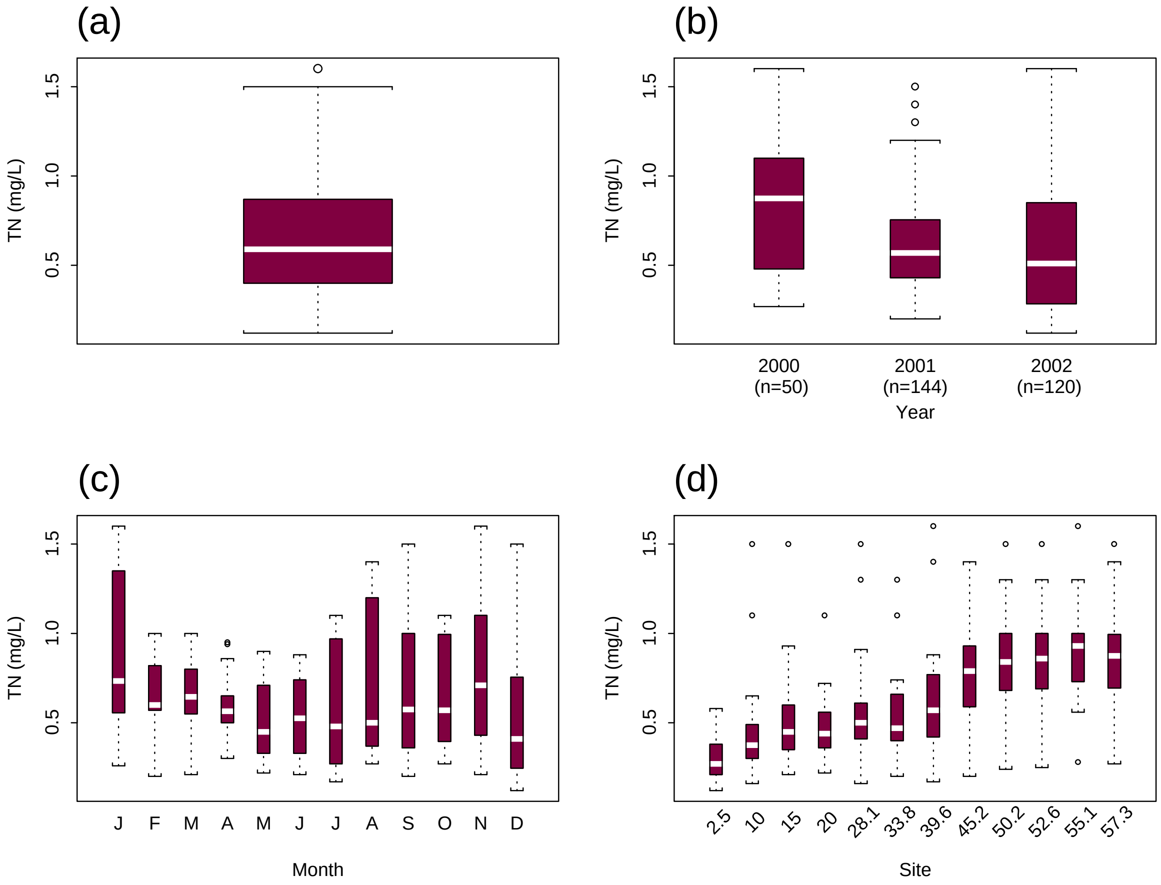

Figure 8: Boxplots of Total Nitrogen (mg/L) for (a) all data, (b) years, (c) months, and (d) sites

A handful of large TP values cause skewness in the distribution of TP; see Figure 9(a). Figure 9(b) indicates that the median effect of TP in 2000 is higher than in the other two years, but that this difference is most likely not significant. There was also smaller variability about the median TP values for 2001 and 2002. From Figure 9(c) we observe that there was not much of a seasonal effect on TP, with median levels fluctuating between 0.1 mg/L and 0.2 mg/L. The variability (IQR) was also quite similar in all months except for February, which was considerably smaller (and six outliers were identified), and November, which was marginally larger. Figure 9(d) indicates that there appears to be a site effect, with TP median and range generally decreasing the further away from the barrage the site is. The corresponding variability (IQR) changes only marginally. Quite a number of anomalous observations have been identified throughout the estuary.

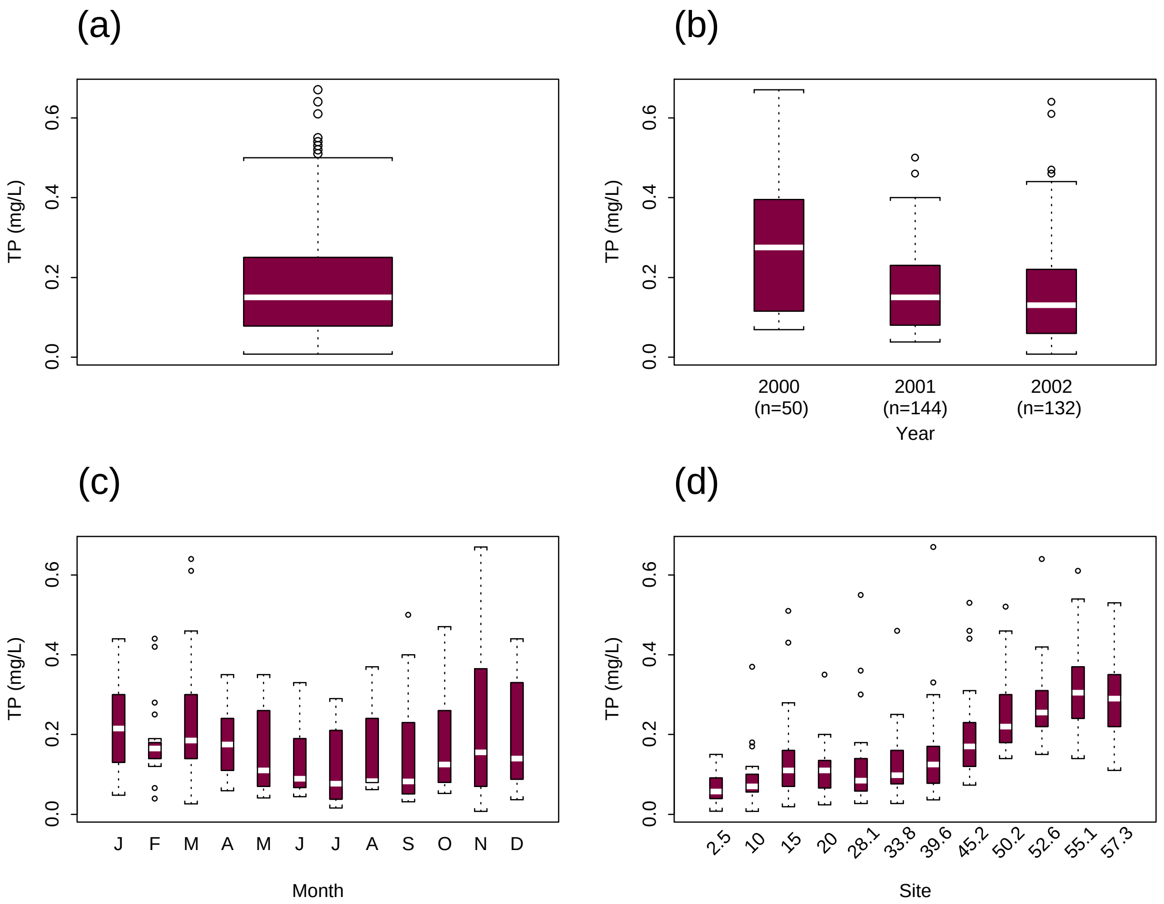

Figure 9: Boxplots of Total Phosphorus (mg/L) for (a) all data, (b) years, (c) months, and (d) sites

The logarithms of Turbidity values, log(Turb), form an approximate Normally-distributed boxplot; see Figure 10(a). Log(Turb) was higher in 2000 than in 2001 and 2002 (Figure 10b), but this is most likely not significant. There is an apparent seasonal effect on turbidity, with higher levels occurring in summer months and lowest in winter months. The variability of the March values is very small, possibly reflecting the fact that turbidity was only recorded in March in the year 2000 (at nine sites). Figure 10(d) highlights that there is potentially a site effect, with higher turbidity levels occurring at sites closer to the river mouth. Variability is greater at sites upstream near the barrage. We see that the levels of log(Turb) are lower at site 28.1 compared to the level at the upstream site and that at the downstream site, which supports our earlier discussion that site 28.1 has less flow due to the ox-bow being broken.

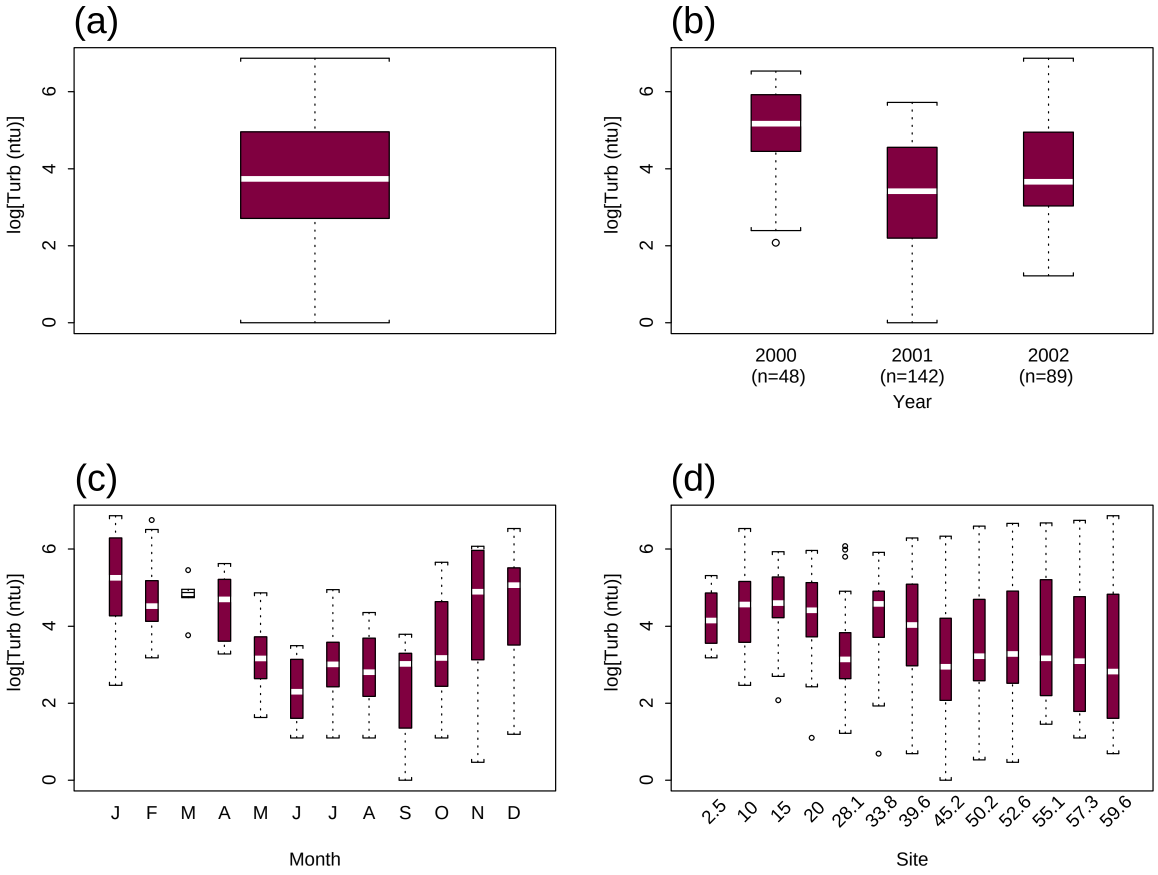

Figure 10: Boxplots of logarithm of Turbidity (ntu) for (a) all data, (b) years, (c) months, and (d) sites

4.1.3 Correlations

The between-site correlation matrices for each water quality variable are provided in Appendix 3. Due to the symmetrical nature of the matrices and for ease of interpretation, we have only presented the lower triangular part of the matrix. Temp and EC measurements were highly correlated between sites, with correlations generally greater than 0.95. There was high degree of correlation between Turb recordings at the lower four sites (2.5, 10, 15 and 20), ranging from 0.65 to 0.84 ($p<0.01$), and a higher degree between the upper six sites (45.2, 50.2, 52.6, 55.1, 57.3 and 59.6), ranging from 0.82 to 0.97 ($p < 0.001$), which perhaps reflects the extent of localised sediment inputs into the estuary.

For TN, TP, FRP, NOX, and NH4, correlation between sites generally decreased with an increase in distance between sites, although there were a few moderate correlations (between 0.3 and 0.5) for NH4 and TP between the very upper sites and the very lower sites. This may be due to the fact that there is some temporal dependence in the system for these variables, which hasn't been taken into account in producing these site-to-site correlations.

4.2 Site and sampling time similarity

4.2.1 Biplots

The biplots displayed in Figure 11-19 enable us to simultaneously examine the separation of the 13 sites and 36 sampling times according to the value of all nine water quality variables. Both median monthly flows and standard errors of monthly flow have been plotted as a more meaningful representation of the sampling times (i.e. month by year combinations). However, we recognise that there are many options for labelling the biplots and there may be scientific justification for choosing a different labelling option.

The main features of each of these biplots have been discussed. Note that the occurrence of NA's in some biplots is due to the corresponding flow data not being available on several sampling occasions. To assist with interpreting the biplots, plots of the second component loadings and tables of the importance of the principal components are provided for each water quality variable in Appendix 4.

According to DO%sat measurements (Figure 11), we observe that there appears to be a clustering of sites into three groups: the lower estuary sites (between 2.5 and 28.1), the middle site (33.8), and the upper estuary sites (between 39.6 and 59.6). There does not appear to be any clustering of times based on the median monthly flow (Figure 11a) or monthly standard error of flow (Figure 11b). The biplots indicate that the temporal variation is greater than the spatial variation, and the first two components account for 80% of the total spatial and temporal variation. The associated loadings of each site indicate that the lower four sites and two of the upper sites have most influence on the total variation explained. The lengths of the site vectors in Figure 11 are similar, indicating that the variation in DO%sat at each site is similar.

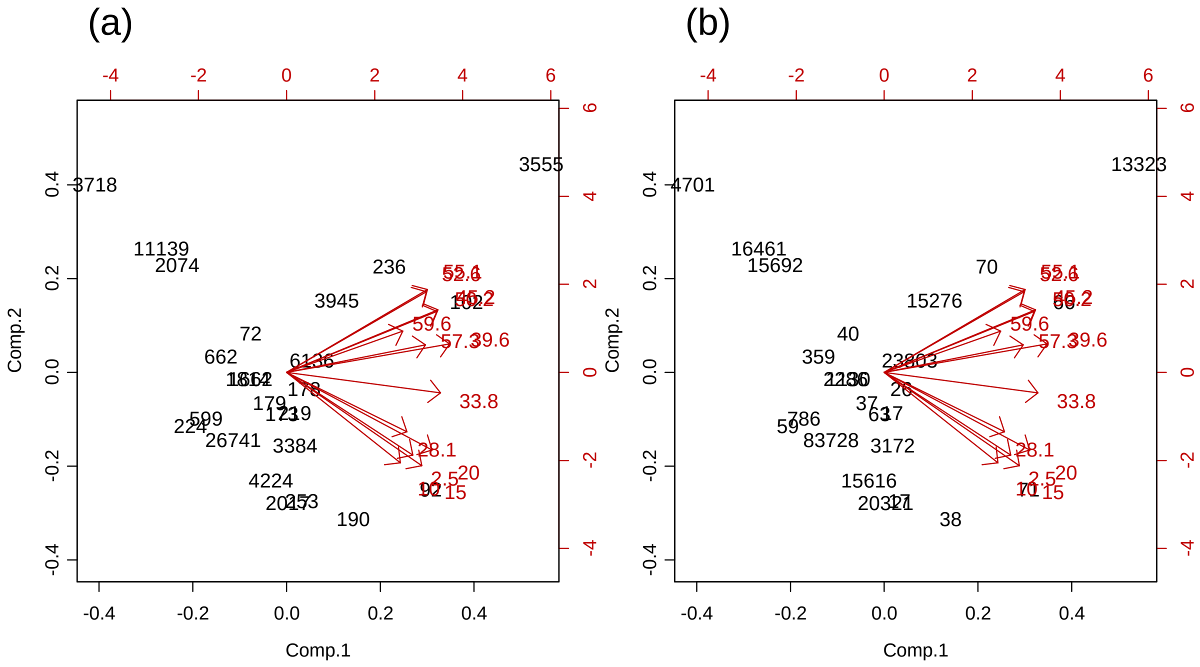

Figure 11: Biplot of Dissolved Oxygen labelled by (a) monthly median flows, and (b) monthly standard errors of flow

Figure 12 indicates that there is some clustering of sites according to Electrical Conductivity, namely the three lower estuary sites (2.5, 10, 15), the ox-bow sites (between 20 and 39.6), and the five upper estuary sites (between 45.2 and 59.6) form three groups. We also observe that there may be some clustering of times according to whether there were small or large variations in the daily flows above the barrage (Figure 12b), but very little indication of clustering of times based on the monthly median flows (Figure 12a). The plot also indicates that the spatial variation is much smaller than the temporal variation, which is reflected in Figure 3. The first two components of the Principal Components Analysis explain 93% of the variation in the Electrical Conductivity data, and by examining the associated loadings we see that most weight is given to the three lower sites in the estuary.

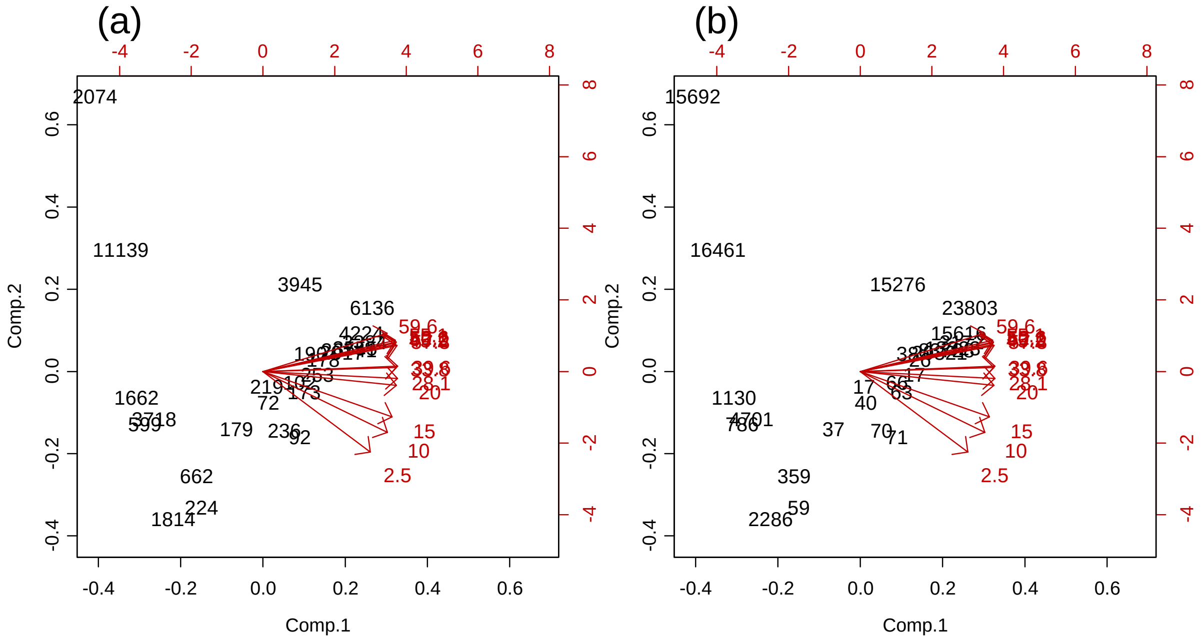

Figure 12: Biplot of Electrical Conductivity labelled by (a) monthly median flows, and (b) monthly standard errors of flow

One observation, with low monthly median flow and associated low standard error, is prominent in Figure 13, but was not flagged as a potential outlier in the boxplots of Temperature displayed in Figure 7. It is therefore difficult to justify removing this time point from the multivariate analyses, so our inferences are based on the analyses that include it.

Apart from the isolation of this one time point, there is greater temporal variation than spatial variation in Temperature (Figure 13). This is supported by the boxplots of Temperature for months (Figure 7c) and sites (Figure 7d). The first two principal components explain 93% of the variation in the Temperature data; the first component alone explained 86% of the variation. There does not seem to be any clustering of times (according to monthly median flow [Figure 13a] or the standard error of flow for a month [Figure 13b]) but there appears to be a clustering of sites into two groups: one comprising sites 2.5, 15, 39.6, 50.2 and 57.3 and the other comprising the remaining sites. This does not appear to be a meaningful and scientifically sensible grouping and is probably just an artefact of the data having little spatial variation. The site vectors are of similar magnitude implying that the variation at each site is similar; this was also observed in Figure 7(d).

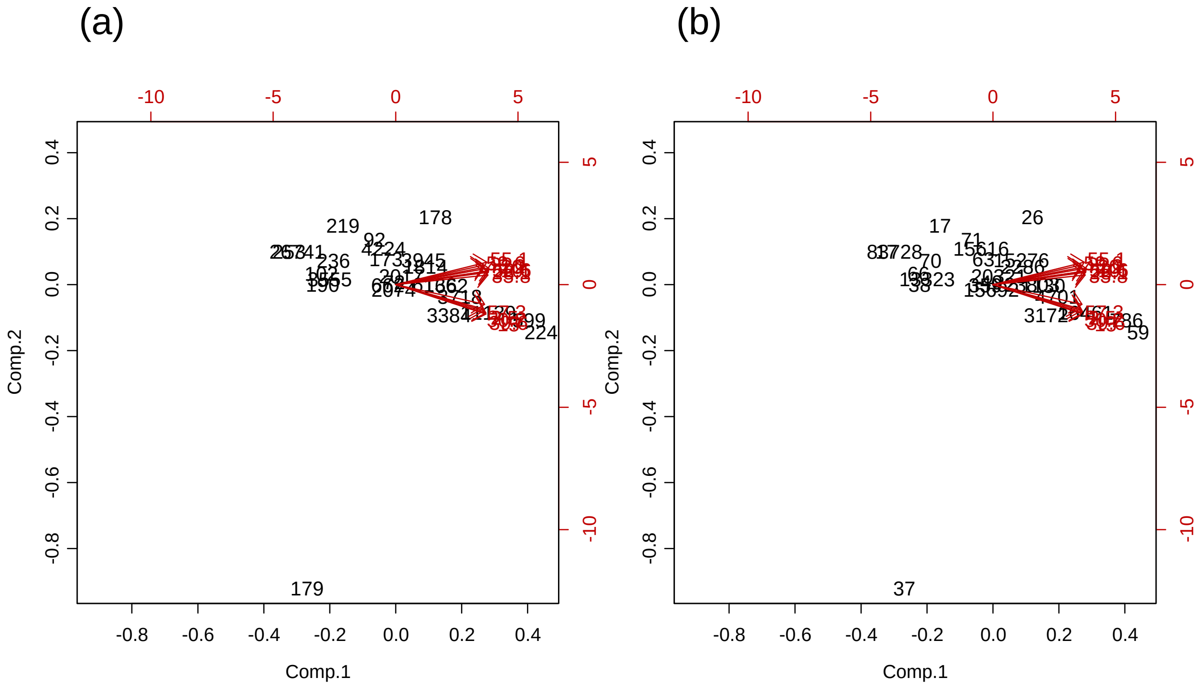

Figure 13: Biplot of Temperature labelled by (a) monthly median flows, and (b) monthly standard errors of flow

Figure 14 indicates that there are two groupings of sites in relation to Turbidity: a loose grouping of sites 2.5 to 39.6; and a tighter grouping of the remaining sites. There does not appear to be any grouping of time based on either the monthly median flows (Figure 14a) or the monthly standard errors of flow (Figure 14b). The first two principal components explain 80% of the data and the loadings suggest that this is mainly due to the variation of the lower four sites in the estuary. The lengths of the vectors are similar, reflecting the similarity of the variation in Turbidity at each site.

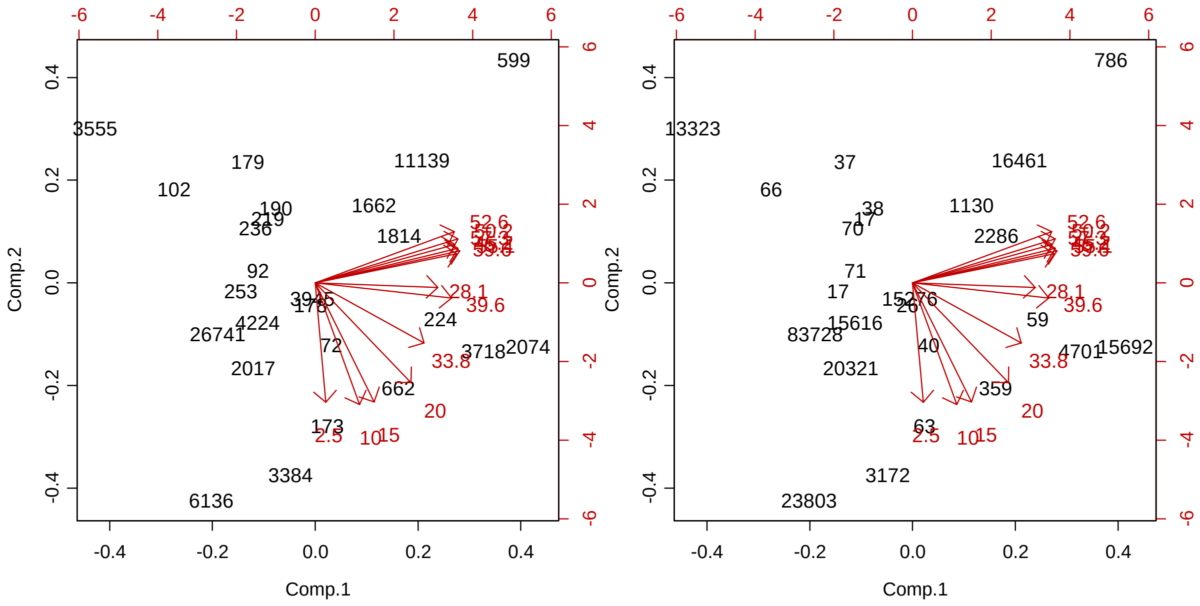

Figure 14: Biplot of the logarithm of Turbidity labelled by (a) monthly median flows, and (b) monthly standard errors of flow

Figure 15 indicates a generally even separation of sites according to variation in Total Nitrogen measurements, with two loose groupings: sites between 2.5 and 39.6, and the remaining sites. There is no clear clustering of times based on the flows in either Figure 15(a) or Figure 15(b). About 85% of the spatial and temporal variation in Total Nitrogen is explained through the first two principal components, and the degree of variation in Total Nitrogen is similar at all sites.

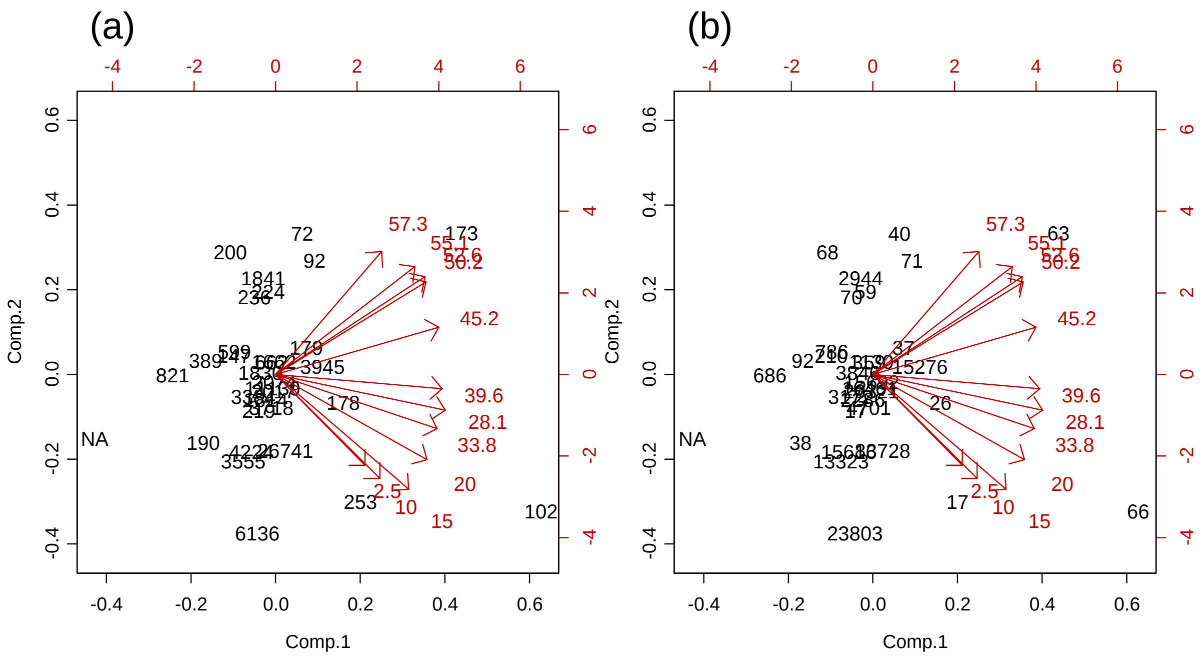

Figure 15: Biplot of Total Nitrogen labelled by (a) monthly median flows, and (b) monthly standard errors of flow

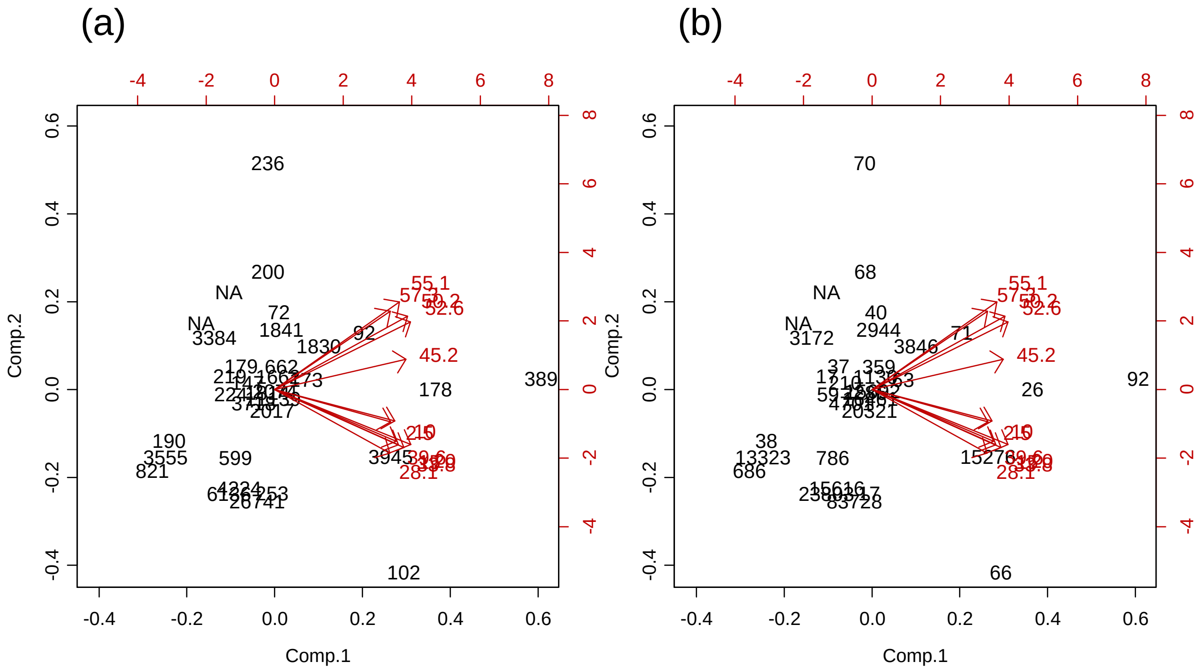

Figure 16: Biplot of Nitrogen Oxides labelled by (a) monthly median flows, and (b) monthly standard errors of flow

Sites cluster into three groups according to the variation in Nitrogen Oxides (see Figure 16). These groups comprise the lower estuary sites (between 2.5 and 39.6), site 45.2, and the upper estuary sites (between 50.2 and 57.3). There is no apparent clustering of sampling times according to the flow. The first two components explain 80% of the spatial and temporal variation in Nitrogen Oxides, and the second component loadings suggest that the upper four sites have most impact on the average Nitrogen Oxides level (i.e. at these four sites the most variable NOX levels were recorded, which is supported by Figure 6d).

There are three distinct groups of sites according to the biplots for Ammonium displayed in Figure 17. Specifically, sites 2.5, 10, 15, 20 and 33.8 form a group; sites 39.6 to 57.3 form another group, and site 28.1 forms the third group. There is no obvious clustering of sampling times according to the median monthly flow (Figure 17a) or the monthly standard error of flow (Figure 17b). About 75% of the variation in Ammonium is explained through the first two principal components.

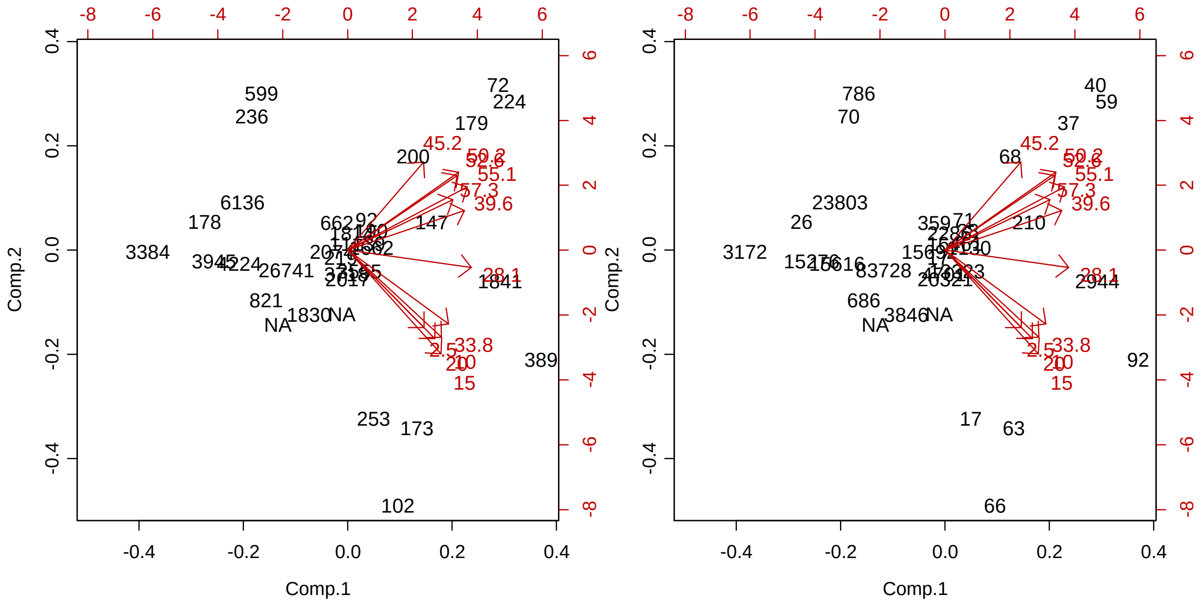

Figure 17: Biplot of logarithm of Ammonium labelled by (a) monthly median flows, and (b) monthly standard errors of flow

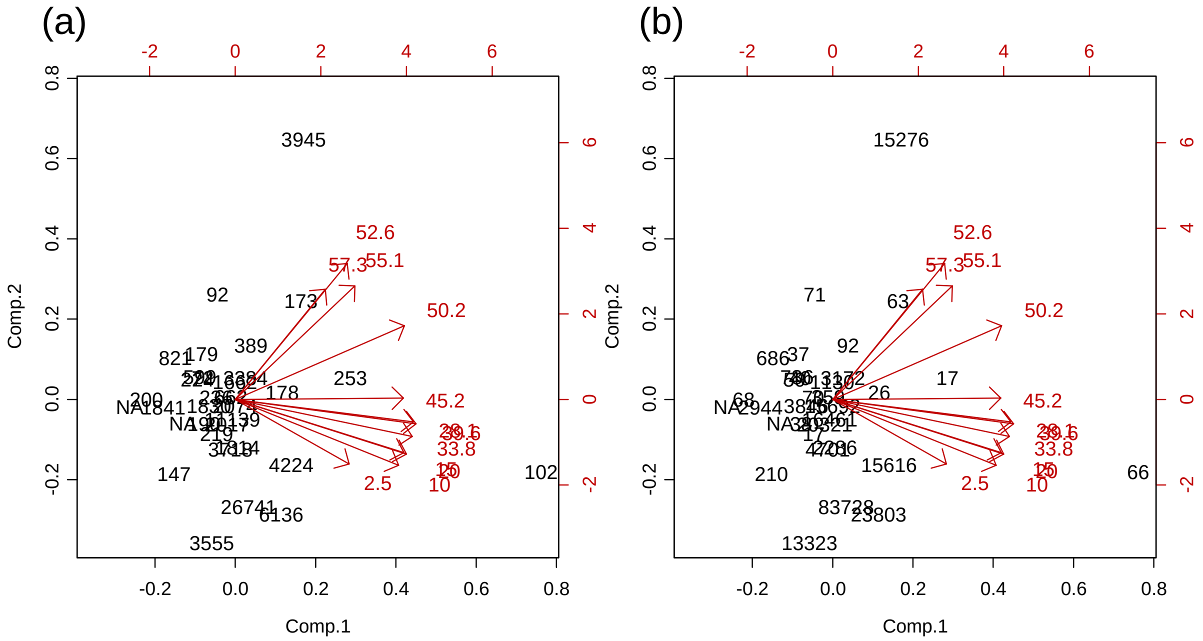

Figure 18: Biplot of Total Phosphorus labelled by (a) monthly median flows, and (b) monthly standard errors of flow

According to the Principal Component Analysis of Total Phosphorus, 78% of the total spatial and temporal variation is explained through the first two components. The groupings of sites are determined by the second component in which the loadings of the upper four sites have most influence on the average (Figure 18). There are three apparent groupings of sites, namely the upper three sites 52.6 to 57.3; site 50.2; and the remaining sites (2.5 to 45.2). However, times, represented by monthly median flows (Figure 18a) and monthly standard errors of flow (Figure 18b), show no apparent clustering.

The first two principal components explain 74% of the total spatial and temporal variation in Filtered Reactive Phosphorus measurements recorded in the estuary between January 2000 and December 2002. The second component loadings suggest that the upper five sites have most influence on the average FRP level and the boxplots in Figure 4(d) indicate that FRP recorded at these sites is higher and more variable than at the sites further downstream. There are two clusterings of sites, according to the biplots in Figure 19: sites 2.5 to 39.6, and sites 45.2 to 57.3. This is confirmed by the site boxplots of FRP displayed in Figure 4(d). There is no apparent clustering of times according to the magnitude of median monthly flows (Figure 19a) or monthly standard error of flow (Figure 19b).

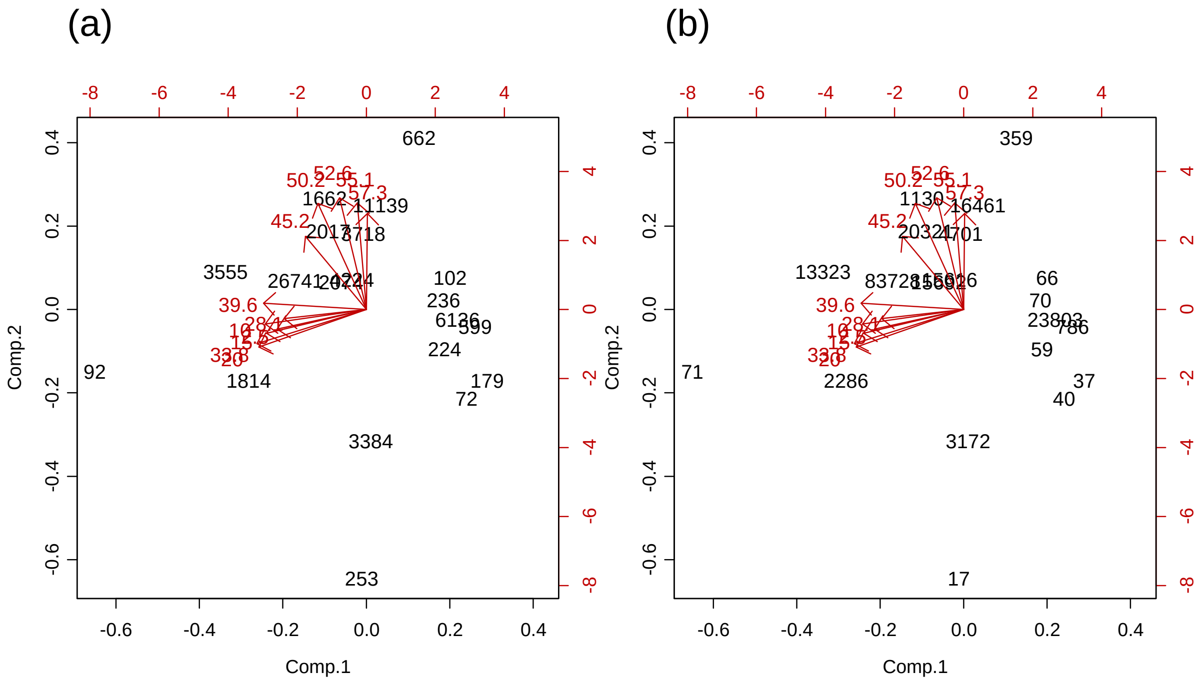

Figure 19: Biplot of Filtered Reactive Phosphorus labelled by (a) monthly median flows, and (b) monthly standard errors of flow

4.2.2 Dendrograms

To complement the biplots displayed and discussed in Section 4.2.1, dendrograms for sites and month by year combinations have been produced for each water quality variable and are provided in Appendix 5. Interpretation of these dendrograms is not provided within the text of this report as the patterns displayed by the dendrograms provide very similar interpretations to those given for the biplots. However, we thought for completeness and to avoid repetition of interpretation, that we would include the dendrograms in an appendix. Additionally, we felt the readership may still prefer to see the clustering solutions.

5 Conclusions

The analyses and results presented in this report were undertaken within a limited project scope, and consequently represent a satisfactory preliminary insight into the collated water quality data. Whilst the data were quite complex, incomplete (unbalanced) and unreplicated, we were able to make headway with a subset of this data to produce useful and sensible inferences, and thus form our recommendations for future water quality monitoring of the Fitzroy River estuary.

Due to the patchiness of when, where and which of the nine water quality variables were recorded, we have been cautious with some of our inferences about particular seasonal (month) and year effects on some of the water quality variables. In particular, during the year 2000, samples were taken in only limited months and not all water quality variables were recorded at each sampling occasion. Thus the total number of observations recorded in 2000 was much smaller than in the following two years. The sample sizes become even smaller if inferences about months or sites in 2000 are of interest. Taking this into account, there did not seem to be any short-term differences in water quality between years. To determine long-term effects such as El Nino, we require the availability of a much longer time series of water quality data.

There were potential seasonal (month) effects on all water quality variables except the two Phosphorus variables, with the nature of the pattern depending on the variable. Likewise, there were potential site effects for all water quality variables except Temp and DO%sat, namely the Nitrogen and Phosphorus levels were highest near the barrage and the EC and Turb levels were highest near the river mouth. We noted a marked change in all of the Nitrogen and Turb levels between sites 39.6 and 45.2. It was beyond the scope of our objectives to formally test whether this change was significant.

In general, the correlation of Nitrogen and Phosphorus water quality levels decreased with an increase in distance between sites, whereas Temp and EC measurements recorded at all sites were highly positively correlated. In calculating the correlation of Turb measurements, we identified localised correlation patterns, namely measurements at sites near the mouth of the river were correlated and measurements at sites near the barrage were correlated.

Taking into account the magnitude of medians and IQRs as displayed in the site boxplots, and site groupings as displayed in the biplots, there appears to be a clustering of sites into either two or three groups, with group membership depending on the water quality variable. Generally, the sites near the mouth of the river formed a group and the sites near the barrage formed a group. Occasionally, the sites in the middle formed their own group. This conclusion is supported by the dynamics of the system - the nature of flushing and mixing in the estuary is different at the river mouth compared to near the barrage. Temp was the only variable where the site groups did not appear to be meaningful. In all cases, the temporal variation was much greater than the spatial variation and there was no apparent clustering of sampling times based on either the median monthly flow or the monthly standard error of flow recorded above the barrage.

The lack of real replication of samples at both sites and times is an issue when calculating uncertainties about estimates. In particular, we note that the statistics associated with some months are only based on one observation, and therefore have high uncertainty.

Tides will certainly have some role in the water quality as will river flow over the barrage, however this information was not available to incorporate into the analyses. We attempted to utilise the flow data recorded above the barrage to explain any potential clusterings of sampling times, but in almost all biplots (Figure 11-19), there didn’t seem to be any clustering of time. A more meaningful flow summary, such as median flow in the previous month or median yearly flow, may be of more use in attempting to interpret the clustering of times.

On their webpage (http://www.coastal.crc.org.au/fitzroy/index.html, 31 July 2003), the Coastal CRC claim that the estuary near Rockhampton has high nutrient levels, which is probably attributable to little tidal mixing due to the barrage, and to sewage outfalls. The boxplots of the chemical water quality variables confirm that there are higher nutrient levels at the upper 4-5 sites as compared to the levels recorded at the other sites further downstream in the estuary.

6 Recommendations

Based on the analyses and interpretations summarised in this report and the conclusions reached, we make the following recommendations for future ambient monitoring of the Fitzroy River “below the barrage”:

1. The number of sites can be reduced to **seven**: **three** in the upper estuary (say, above 45.2AMTD), **two** in the lower estuary (say, below 20AMTD), and **two** in the vicinity of the ox-bow (say, between 20AMTD and 33.8AMTD). If Turbidity is of key interest, then we recommend increasing your spatial intensity in the lower reach of the river, to capture the greatest levels and variability in Turbidity occurring throughout the estuary. On the other hand, if chemical water quality variables are of key interest, and in particular, if monitoring their magnitude in relation to the inputs to the system from the STPs is of importance, then we recommend increasing your spatial intensity in the upper reach of the river, to capture the greatest levels and variability of these variables recorded throughout the estuary.
2. The sampling frequency remains **monthly**. There is not enough data (as provided) and thus evidence, to support a decrease or increase in the sampling frequency.
3. A pilot sampling survey is undertaken throughout the estuary where a minimum of **five** samples is collected at each site during each month. This will primarily enable calculation of a “true” variance for each site (i.e. within-site variability) during these times and subsequent confidence limits about the estimates. Future analysis of the measurements from the five replicate samples will then also enable the optimal replication level to be determined for the variables of interest. For example, the outcome of this may indicate that sampling should be carried out more intensively in high flow periods than in low flow periods.
4. Relevant hydrological data, collected at the time of sampling, would enhance the analyses undertaken. These might include tidal data, such as flow of

water and whether the tide is outgoing or incoming; and measurable flow inputs into the estuary such as that through the barrage. Data of this nature would help to calibrate the water quality measurements in the estuary.

7 Future Directions

Our preliminary investigations in preparing this report indicate that there are many other aspects of this data worth exploring and modelling. Such investigations were beyond the scope of this work, but we have provided bullet points for future consideration:

- Spatial-temporal modelling of water quality, accounting for known effects (i.e. predictor variables), such as season, tidal levels, upstream flow input, STP and fish ladder inputs, site, depth, and values of other water quality variables. This would enable us to quantify both the spatial and temporal dependence of water quality remaining in the system after accounting for known effects, and investigate and quantify the relationship between water quality and the known effects. This type of model would provide the most meaningful and comprehensive picture of water quality over a range of (consecutive) months and years, and sites. These models should also be subjected to cross-validation, which would be useful in checking the predictive accuracy of the model, but would also be useful in establishing what influence each site and sampling frequency has on the model parameters (i.e. by leaving out one site or sampling time, we can refit the model and compare parameter estimates for those common terms). Of course, this form of modelling is really only feasible with large enough sample sizes, which depends on the outcome of the pilot study recommended in Point 3 of Section 6.

- Our analyses presented in this report consider each water quality variable separately. Through multivariate analyses, the pattern of similarity/dissimilarity between the nine water quality variables could be investigated and quantified. This would also allow us to better understand the interdependencies arising through their interactions.

8 References

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Appendix 1

The Fitzroy River ambient water quality data, which was recorded below the barrage at 13 sites between January 2000 and December 2002 and sampled at a depth of 20 cm, was analysed for this report. Refer to the CD attached to this report for a copy of this data.

Appendix 2

The following tables summarise the numbers of observations in each level of site, month, year, site by month, and site by year. The water quality variables were recorded according to one of three patterns. However, after outliers were removed, there were six unique patterns, and the tabulations for these six patterns of water quality variables are presented. The tables are discussed in Section 4.1.1.

DO%sat

Site	*2.5*	*10*	*15*	*20*	*28.1*	*33.8*	*39.6*	*45.2*	*50.2*	*52.6*	*55.1*	*57.3*	*59.6*
No. obs	19	22	21	22	22	23	20	21	23	22	21	22	20

Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
No. obs	26	26	9	21	22	13	21	20	24	33	34	29

Year	*2000*	*2001*	*2002*
No. obs	48	141	89

	Year		
Month	*2000*	*2001*	*2002*
J	0	13	13
F	0	13	13
M	9	0	0
A	0	13	8
M	0	13	9
J	0	13	0
J	0	13	8
A	0	13	7
S	0	13	11
O	13	12	8
N	13	13	8
D	13	12	4

	Year		
Site	*2000*	*2001*	*2002*
2.5	3	11	5
10	3	11	8
15	3	11	7
20	4	11	7
28.1	3	11	8
33.8	4	11	8
39.6	4	11	5
45.2	4	11	6
50.2	4	11	8
52.6	4	11	7
55.1	4	11	6
57.3	4	11	7
59.6	4	9	7

EC, Temp, Turb

Site	*2.5*	*10*	*15*	*20*	*28.1*	*33.8*	*39.6*	*45.2*	*50.2*	*52.6*	*55.1*	*57.3*	*59.6*
No. obs	19	22	21	22	22	23	20	21	23	22	21	22	21

Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
No. obs	26	26	9	21	22	13	21	20	24	34	34	29

Year	*2000*	*2001*	*2002*
No. obs	48	142	89

	Year		
Month	*2000*	*2001*	*2002*
J	0	13	13
F	0	13	13
M	9	0	0
A	0	13	8
M	0	13	9
J	0	13	0
J	0	13	8
A	0	13	7
S	0	13	11
O	13	13	8
N	13	13	8
D	13	12	4

	Year		
Site	*2000*	*2001*	*2002*
2.5	3	11	5
10	3	11	8
15	3	11	7
20	4	11	7
28.1	3	11	8
33.8	4	11	8
39.6	4	11	5
45.2	4	11	6
50.2	4	11	8
52.6	4	11	7
55.1	4	11	6
57.3	4	11	7
59.6	4	10	7

TN

Site	*2.5*	*10*	*15*	*20*	*28.1*	*33.8*	*39.6*	*45.2*	*50.2*	*52.6*	*55.1*	*57.3*	*59.6*
No. obs	25	26	25	31	25	25	25	25	25	25	25	32	0

Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
No. obs	24	26	26	26	26	24	25	14	26	24	37	36

Year	*2000*	*2001*	*2002*
No. obs	50	144	120

	Year		
Month	*2000*	*2001*	*2002*
J	0	12	12
F	2	12	12
M	2	12	12
A	2	12	12
M	2	12	12
J	0	12	12
J	1	12	12
A	2	12	0
S	2	12	12
O	12	12	0
N	13	12	12
D	12	12	12

Site	*Year* *2000*	 *2001*	 *2002*
2.5	3	12	10
10	4	12	10
15	3	12	10
20	9	12	10
28.1	4	12	10
33.8	4	12	10
39.6	4	12	10
45.2	4	12	10
50.2	4	12	10
52.6	4	12	10
55.1	4	12	10
57.3	10	12	10
59.6	0	0	0

NH4

Site	*2.5*	*10*	*15*	*20*	*28.1*	*33.8*	*39.6*	*45.2*	*50.2*	*52.6*	*55.1*	*57.3*	*59.6*
No. obs	26	26	26	32	26	26	26	26	26	26	26	33	0

Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
No. obs	24	26	26	26	26	24	25	14	26	36	36	36

Year	*2000*	*2001*	*2002*
No. obs	49	144	132

	Year		
Month	*2000*	*2001*	*2002*
J	0	12	12
F	2	12	12
M	2	12	12
A	2	12	12
M	2	22	12
J	0	22	12
J	1	12	12
A	2	12	0
S	2	12	12
O	12	12	12
N	22	12	12
D	12	12	12

	Year		
Site	*2000*	*2001*	*2002*
2.5	3	12	11
10	3	12	11
15	3	12	11
20	9	12	11
28.1	3	12	11
33.8	3	12	11
39.6	3	12	11
45.2	3	12	11
50.2	3	12	11
52.6	3	12	11
55.1	3	12	11
57.3	10	12	11
59.6	0	0	0

NOX, TP

Site	*2.5*	*10*	*15*	*20*	*28.1*	*33.8*	*39.6*	*45.2*	*50.2*	*52.6*	*55.1*	*57.3*	*59.6*
No. obs	26	26	26	32	26	26	26	26	26	26	26	34	0

Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
No. obs	24	26	26	26	26	24	25	14	26	36	37	36

Year	*2000*	*2001*	*2002*
No. obs	50	144	132

	Year		
Month	*2000*	*2001*	*2002*
J	0	12	12
F	2	12	12
M	2	12	12
A	2	12	12
M	2	12	12
J	0	12	12
J	1	12	12
A	2	12	0
S	2	12	12
O	12	12	12
N	13	12	12
D	12	12	12

	Year		
Site	*2000*	*2001*	*2002*
2.5	3	12	11
10	3	12	11
15	3	12	11
20	9	12	11
28.1	3	12	11
33.8	3	12	11
39.6	3	12	11
45.2	3	12	11
50.2	3	12	11
52.6	3	12	11
55.1	3	12	11
57.3	11	12	11
59.6	0	0	0

FRP

Site	*2.5*	*10*	*15*	*20*	*28.1*	*33.8*	*39.6*	*45.2*	*50.2*	*52.6*	*55.1*	*57.3*	*59.6*
No. obs	17	18	19	20	20	20	20	20	20	20	20	20	0

Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
No. obs	12	12	12	12	22	22	24	12	24	24	34	24

Year	*2000*	*2001*	*2002*
No. obs	10	92	132

	Year		
Month	*2000*	*2001*	*2002*
J	0	0	12
F	0	0	12
M	0	0	12
A	0	0	12
M	0	10	12
J	0	10	12
J	0	12	12
A	0	12	0
S	0	12	12
O	0	12	12
N	10	12	12
D	0	12	12

	Year		
Site	*2000*	*2001*	*2002*
2.5	0	6	11
10	1	6	11
15	0	8	11
20	1	8	11
28.1	1	8	11
33.8	1	8	11
39.6	1	8	11
45.2	1	8	11
50.2	1	8	11
52.6	1	8	11
55.1	1	8	11
57.3	1	8	11
59.6	0	0	0

Appendix 3

The following tables summarise the Spearman rank correlations between sites for each water quality variable and are discussed in Section 4.1.3.

2.5	1.00												
10	0.65	1.00											
15	0.51	0.82	1.00										
20	0.44	0.68	0.68	1.00									
28.1	0.62	0.83	0.92	0.72	1.00								
33.8	0.76	0.66	0.81	0.61	0.62	1.00							
39.6	0.44	0.48	0.47	0.35	0.66	0.41	1.00						
45.2	-0.18	-0.09	0.01	-0.02	0.40	-0.05	0.69	1.00					
50.2	0.26	0.20	0.26	0.11	0.52	0.25	0.58	0.58	1.00				
52.6	0.25	0.09	0.24	0.18	0.48	0.20	0.64	0.60	0.88	1.00			
55.1	0.54	0.45	0.37	0.22	0.62	0.37	0.71	0.51	0.78	0.81	1.00		
57.3	0.35	0.57	0.39	0.08	0.52	0.23	0.67	0.28	0.50	0.43	0.66	1.00	
59.6	-0.48	0.18	0.08	0.13	0.04	-0.31	-0.28	0.13	-0.27	-0.20	-0.34	-0.17	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**	**59.6**

Between-site correlations for Dissolved Oxygen (%saturation)

2.5	1.00												
10	0.99	1.00											
15	0.99	1.00	1.00										
20	0.99	0.99	0.99	1.00									
28.1	0.97	0.97	0.97	0.99	1.00								
33.8	0.99	0.99	0.99	0.99	0.98	1.00							
39.6	0.99	1.00	1.00	1.00	0.99	1.00	1.00						
45.2	0.98	0.98	0.99	0.99	0.98	0.99	0.99	1.00					
50.2	0.99	0.99	1.00	0.99	0.98	0.99	1.00	0.99	1.00				
52.6	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	1.00			
55.1	0.97	0.97	0.97	0.97	0.99	0.97	0.98	0.97	0.98	0.99	1.00		
57.3	0.96	0.95	0.96	0.95	0.97	0.96	0.97	0.95	0.97	0.98	0.99	1.00	
59.6	0.94	0.96	0.96	0.95	0.97	0.96	0.97	0.98	0.98	0.98	0.99	0.99	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**	**59.6**

Between-site correlations for Temperature

2.5	1.00												
10	0.80	1.00											
15	0.67	0.83	1.00										
20	0.65	0.74	0.84	1.00									
28.1	0.07	0.24	0.36	0.56	1.00								
33.8	0.20	0.26	0.58	0.70	0.75	1.00							
39.6	0.06	0.19	0.40	0.59	0.88	0.79	1.00						
45.2	-0.10	0.05	0.24	0.38	0.67	0.42	0.88	1.00					
50.2	-0.17	0.09	0.15	0.38	0.55	0.35	0.71	0.97	1.00				
52.6	-0.19	0.07	0.15	0.31	0.58	0.35	0.68	0.94	0.97	1.00			
55.1	-0.09	0.14	0.23	0.34	0.69	0.42	0.73	0.91	0.93	0.97	1.00		
57.3	-0.04	0.24	0.21	0.27	0.63	0.41	0.65	0.82	0.87	0.94	0.96	1.00	
59.6	-0.03	0.03	0.18	0.32	0.74	0.42	0.77	0.94	0.91	0.96	0.96	0.93	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**	**59.6**

Between-site correlations for Turbidity

2.5	1.00											
10	0.75	1.00										
15	0.64	0.89	1.00									
20	0.55	0.72	0.93	1.00								
28.1	0.35	0.60	0.77	0.85	1.00							
33.8	0.37	0.61	0.83	0.91	0.90	1.00						
39.6	0.22	0.37	0.51	0.64	0.83	0.78	1.00					
45.2	0.21	0.26	0.29	0.41	0.68	0.49	0.79	1.00				
50.2	0.10	0.12	0.10	0.26	0.45	0.28	0.56	0.85	1.00			
52.6	0.10	0.11	0.09	0.24	0.40	0.25	0.47	0.78	0.95	1.00		
55.1	0.16	0.07	0.05	0.22	0.34	0.18	0.39	0.72	0.92	0.97	1.00	
57.3	0.07	-0.02	-0.07	-0.04	0.22	0.07	0.28	0.62	0.85	0.94	0.96	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**

Between-site correlation for Total Nitrogen

2.5	1.00											
10	0.76	1.00										
15	0.53	0.82	1.00									
20	0.55	0.70	0.85	1.00								
28.1	0.49	0.57	0.69	0.88	1.00							
33.8	0.49	0.60	0.78	0.93	0.90	1.00						
39.6	0.37	0.40	0.59	0.77	0.89	0.84	1.00					
45.2	0.32	0.32	0.49	0.61	0.78	0.69	0.90	1.00				
50.2	0.29	0.30	0.49	0.49	0.59	0.52	0.67	0.87	1.00			
52.6	0.31	0.31	0.41	0.42	0.50	0.41	0.48	0.68	0.86	1.00		
55.1	0.45	0.23	0.22	0.23	0.21	0.21	0.25	0.38	0.53	0.68	1.00	
57.3	0.33	0.10	0.06	-0.01	0.19	0.16	0.13	0.28	0.48	0.62	0.67	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**

Between-site correlation for Total Phosphorus

2.5	1.00											
10	0.82	1.00										
15	0.83	0.94	1.00									
20	0.86	0.94	0.98	1.00								
28.1	0.53	0.77	0.74	0.77	1.00							
33.8	0.77	0.90	0.94	0.96	0.82	1.00						
39.6	0.52	0.77	0.70	0.76	0.70	0.82	1.00					
45.2	0.15	0.45	0.35	0.33	0.53	0.43	0.66	1.00				
50.2	0.16	0.36	0.29	0.23	0.41	0.30	0.45	0.86	1.00			
52.6	0.11	0.22	0.27	0.11	0.26	0.15	0.26	0.71	0.93	1.00		
55.1	0.24	0.08	0.05	-0.09	-0.07	-0.10	0.03	0.45	0.75	0.76	1.00	
57.3	0.01	-0.13	-0.13	-0.26	-0.17	-0.28	-0.28	0.06	0.48	0.58	0.80	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**

Between-site correlations for Filtered Reactive Phosphorus

2.5	1.00											
10	0.76	1.00										
15	0.75	0.87	1.00									
20	0.74	0.77	0.89	1.00								
28.1	0.49	0.44	0.59	0.73	1.00							
33.8	0.61	0.57	0.70	0.91	0.87	1.00						
39.6	0.50	0.47	0.59	0.81	0.86	0.94	1.00					
45.2	0.28	0.45	0.33	0.56	0.64	0.71	0.79	1.00				
50.2	0.22	0.36	0.18	0.38	0.47	0.51	0.58	0.92	1.00			
52.6	0.25	0.33	0.19	0.39	0.46	0.53	0.60	0.88	0.97	1.00		
55.1	0.20	0.35	0.12	0.30	0.31	0.41	0.45	0.83	0.97	0.96	1.00	
57.3	0.21	0.34	0.14	0.34	0.27	0.43	0.46	0.78	0.92	0.93	0.97	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**

Between-site correlations for Nitrogen Oxides

2.5	1.00											
10	0.80	1.00										
15	0.66	0.82	1.00									
20	0.53	0.78	0.88	1.00								
28.1	0.64	0.82	0.80	0.85	1.00							
33.8	0.53	0.73	0.82	0.94	0.69	1.00						
39.6	0.42	0.56	0.44	0.59	0.66	0.58	1.00					
45.2	-0.19	-0.02	-0.09	0.13	0.38	0.16	0.65	1.00				
50.2	0.03	0.34	0.25	0.28	0.59	0.33	0.65	0.64	1.00			
52.6	0.12	0.22	0.24	0.26	0.52	0.29	0.62	0.64	0.89	1.00		
55.1	0.51	0.47	0.39	0.32	0.63	0.38	0.70	0.59	0.82	0.82	1.00	
57.3	0.40	0.44	0.36	0.17	0.49	0.34	0.75	0.47	0.75	0.70	0.80	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**

Between-site correlations for Ammonium

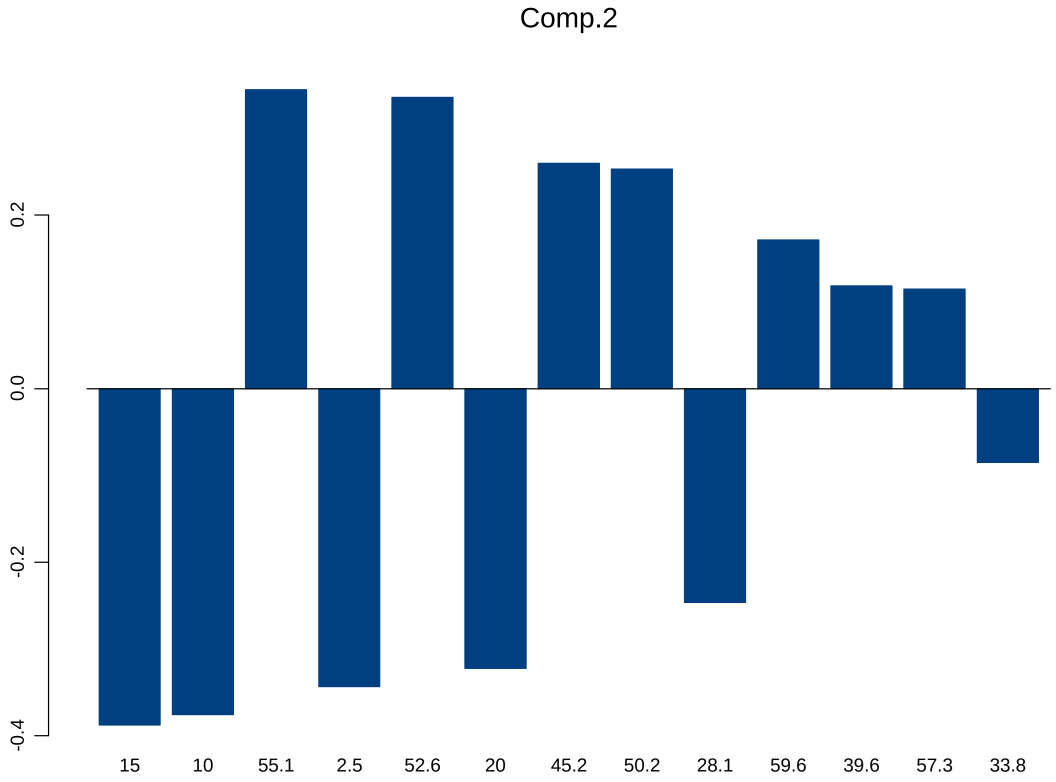
2.5	1.00												
10	0.96	1.00											
15	0.94	0.99	1.00										
20	0.94	0.99	1.00	1.00									
28.1	0.91	0.97	0.98	0.97	1.00								
33.8	0.92	0.98	0.98	0.98	0.99	1.00							
39.6	0.91	0.98	0.98	0.98	0.98	0.99	1.00						
45.2	0.91	0.98	0.98	0.98	0.99	0.99	1.00	1.00					
50.2	0.91	0.99	0.98	0.97	0.99	0.98	0.99	1.00	1.00				
52.6	0.90	0.98	0.99	0.98	0.99	0.99	0.98	0.99	0.99	1.00			
55.1	0.92	0.98	0.99	0.98	0.99	0.98	0.98	0.99	0.99	1.00	1.00		
57.3	0.92	0.98	0.99	0.98	0.99	0.97	0.97	0.98	0.99	0.99	1.00	1.00	
59.6	0.92	0.98	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.99	1.00
	2.5	**10**	**15**	**20**	**28.1**	**33.8**	**39.6**	**45.2**	**50.2**	**52.6**	**55.1**	**57.3**	**59.6**

Between-site correlations for Electrical Conductivity

Appendix 4

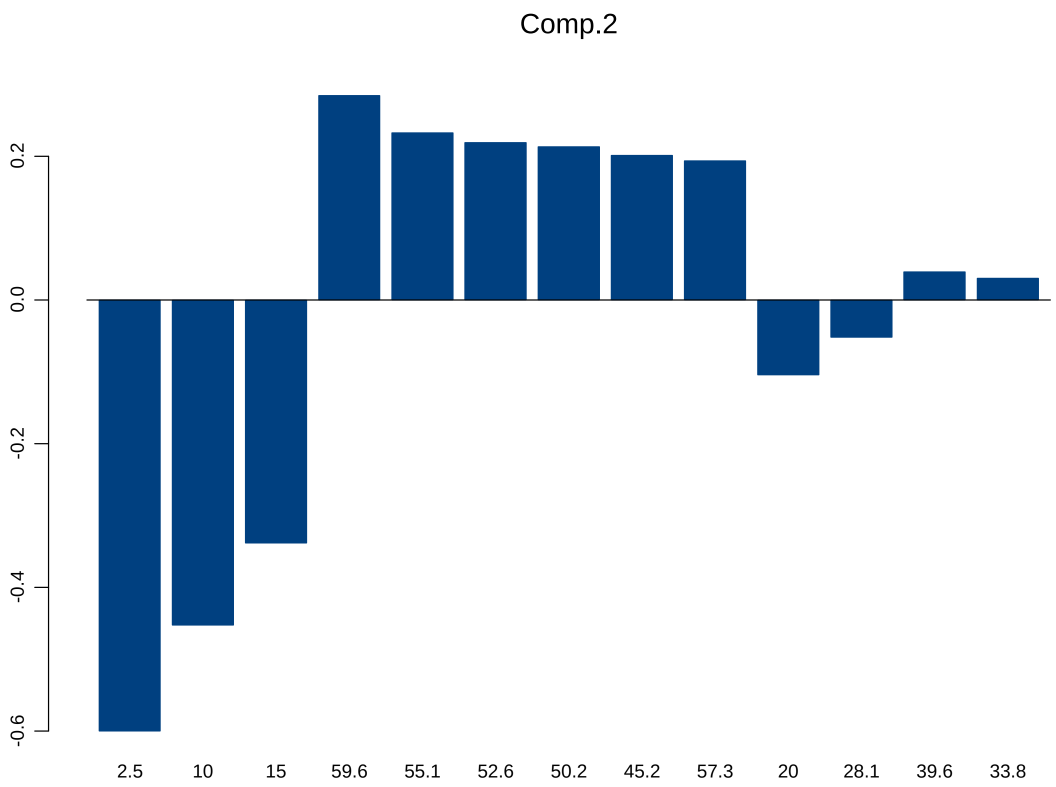
For each water quality variable, we plotted the second principal component loadings as a bar chart and produced a summary of the Principal Component Analysis by listing for each component the standard deviation, the proportion of variation accounted for by each component, and the cumulative proportion of variation accounted for by successive components. These are discussed in Section 4.2.1.

DO%sat



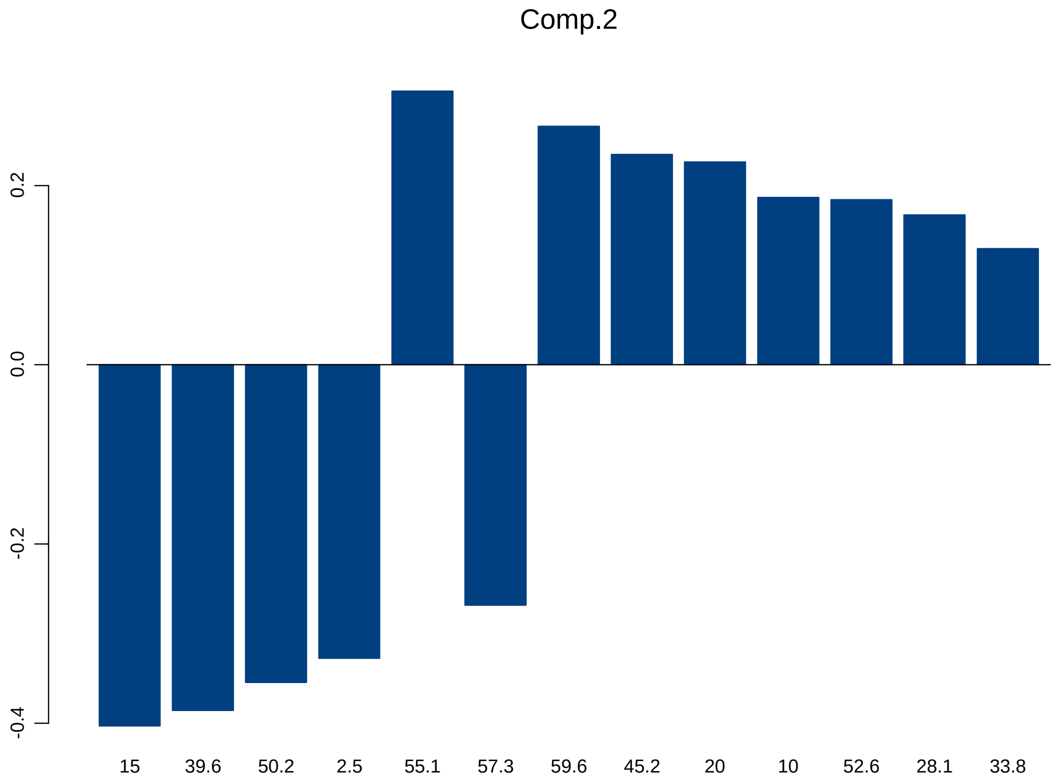
	Component												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Standard Deviation	2.90	1.40	0.94	0.77	0.66	0.50	0.38	0.37	0.26	0.26	0.17	0.14	0.09
Proportion of Variance	0.65	0.15	0.07	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Cumulative Proportion	0.65	0.80	0.87	0.91	0.94	0.96	0.98	0.99	0.99	1.00	1.00	1.00	1.00

EC



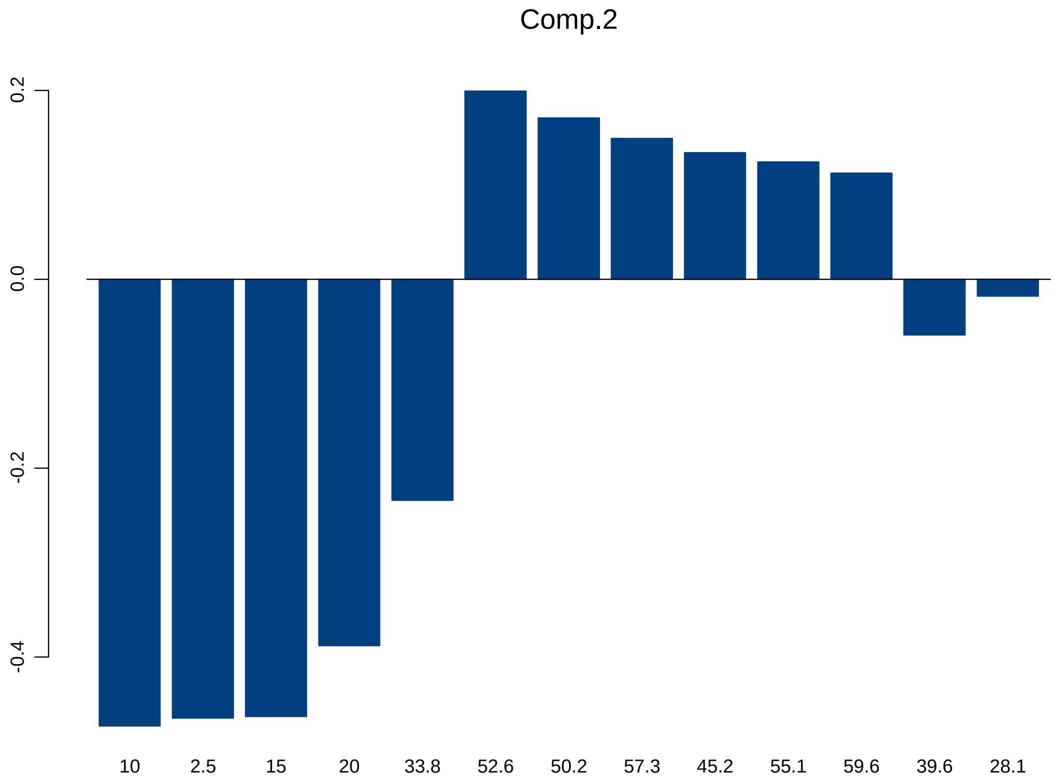
	Component												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Standard deviation	3.34	0.96	0.56	0.47	0.39	0.35	0.22	0.19	0.17	0.10	0.08	0.06	0.02
Proportion of Variance	0.86	0.07	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Proportion	0.86	0.93	0.95	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00

Temp



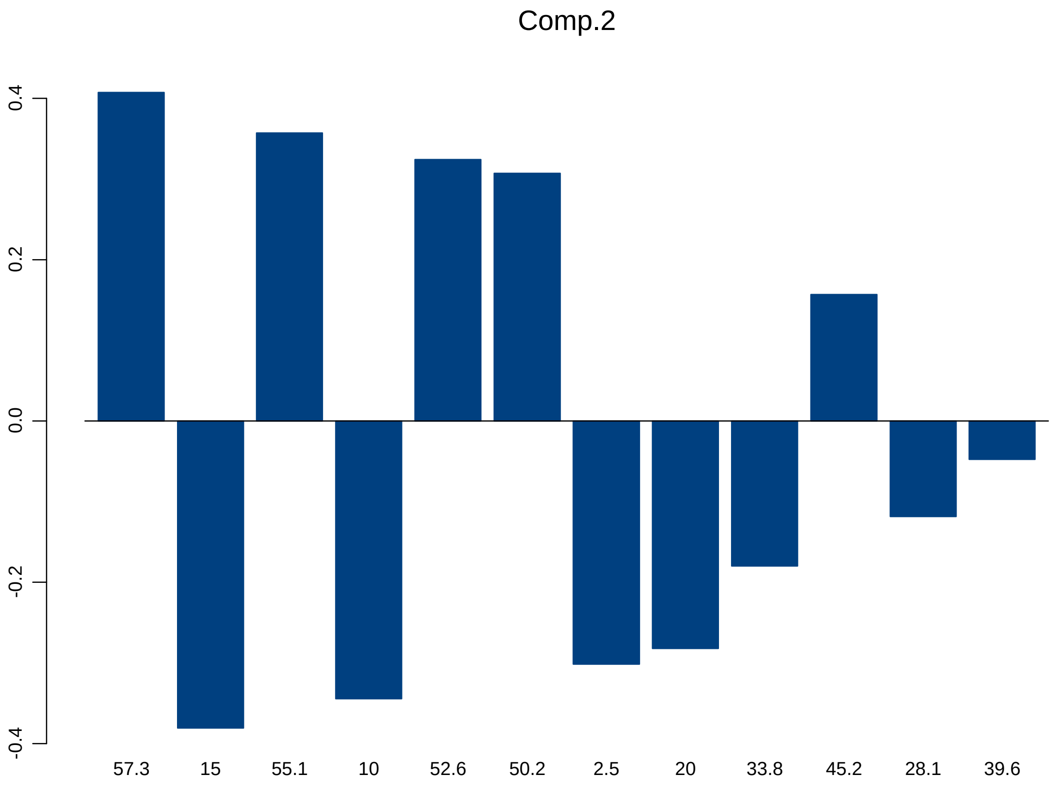
	Component												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Standard deviation	3.40	0.76	0.56	0.48	0.39	0.28	0.19	0.14	0.10	0.09	0.07	0.06	0.03
Proportion of Variance	0.89	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Proportion	0.89	0.93	0.96	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00

log(Turb)



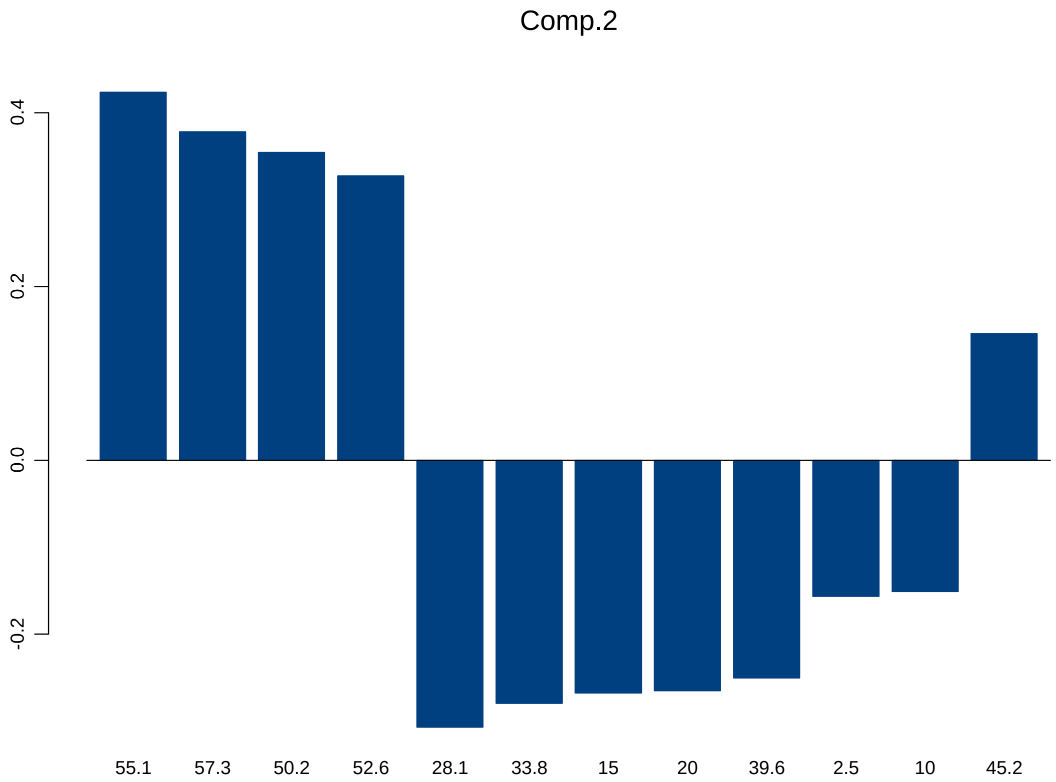
	Component												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Standard deviation	2.79	1.63	0.92	0.86	0.64	0.46	0.34	0.30	0.23	0.20	0.15	0.11	0.06
Proportion of Variance	0.60	0.20	0.07	0.06	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Proportion	0.60	0.80	0.87	0.93	0.96	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00

TN



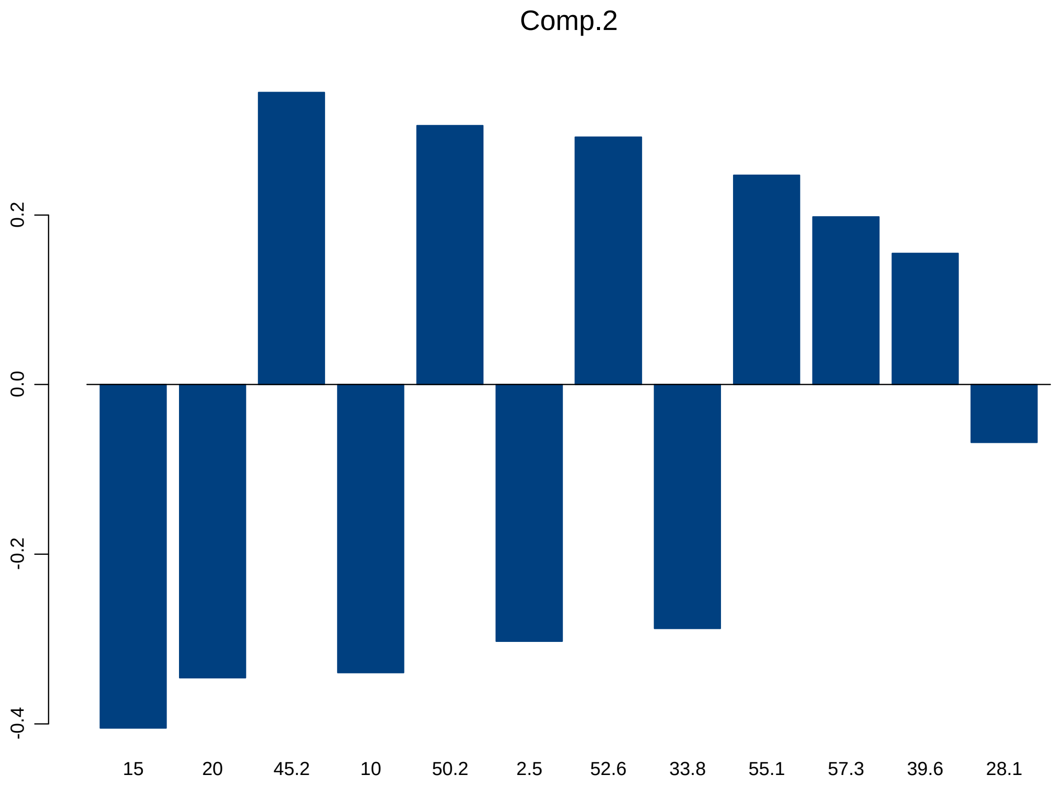
	Component											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Standard deviation	2.72	1.66	0.89	0.66	0.49	0.41	0.28	0.22	0.18	0.16	0.13	0.07
Proportion of Variance	0.62	0.23	0.07	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Proportion	0.62	0.85	0.91	0.95	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00

NOX



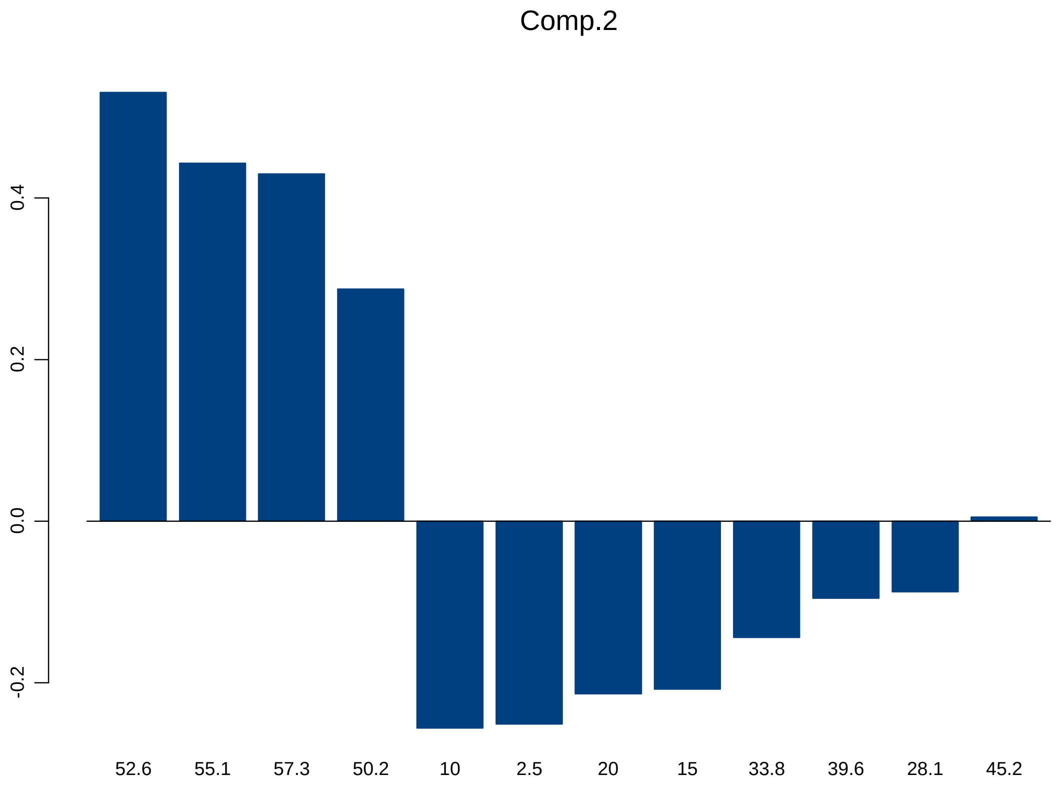
	Component											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Standard deviation	2.80	1.33	1.22	0.55	0.43	0.38	0.30	0.25	0.23	0.17	0.15	0.08
Proportion of Variance	0.65	0.15	0.12	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Cumulative Proportion	0.65	0.80	0.93	0.95	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00

log(NH4)



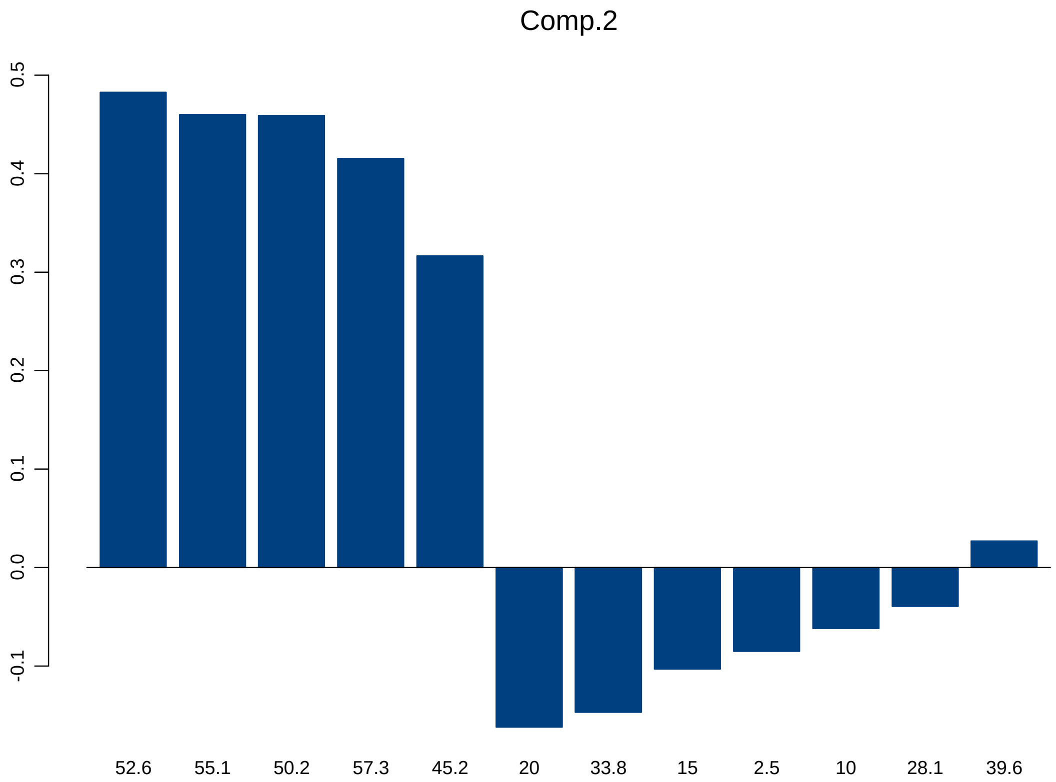
	Component											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Standard deviation	2.32	1.80	1.27	0.85	0.62	0.51	0.38	0.34	0.28	0.20	0.14	0.12
Proportion of Variance	0.45	0.27	0.14	0.06	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00
Cumulative Proportion	0.45	0.72	0.85	0.91	0.94	0.97	0.98	0.99	0.99	1.00	1.00	1.00

TP



	Component											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Standard deviation	2.76	1.32	0.99	0.77	0.60	0.48	0.46	0.36	0.23	0.20	0.19	0.14
Proportion of Variance	0.63	0.15	0.08	0.05	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00
Cumulative Proportion	0.63	0.78	0.86	0.91	0.94	0.96	0.98	0.99	0.99	1.00	1.00	1.00

FRP

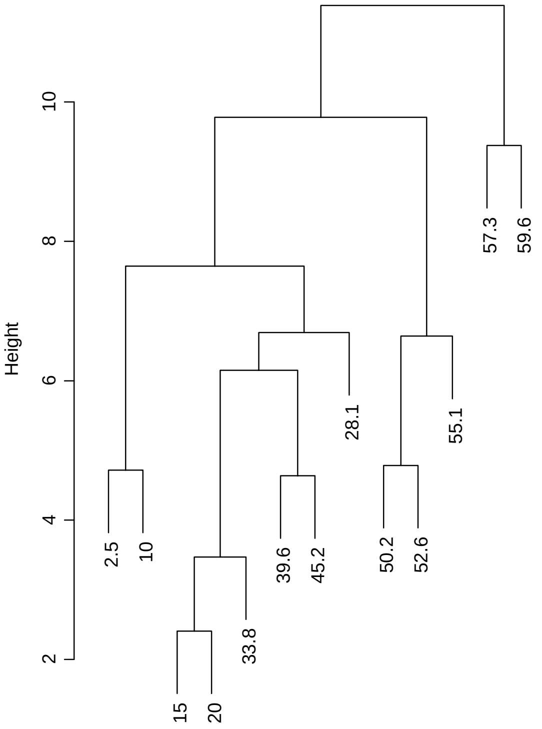


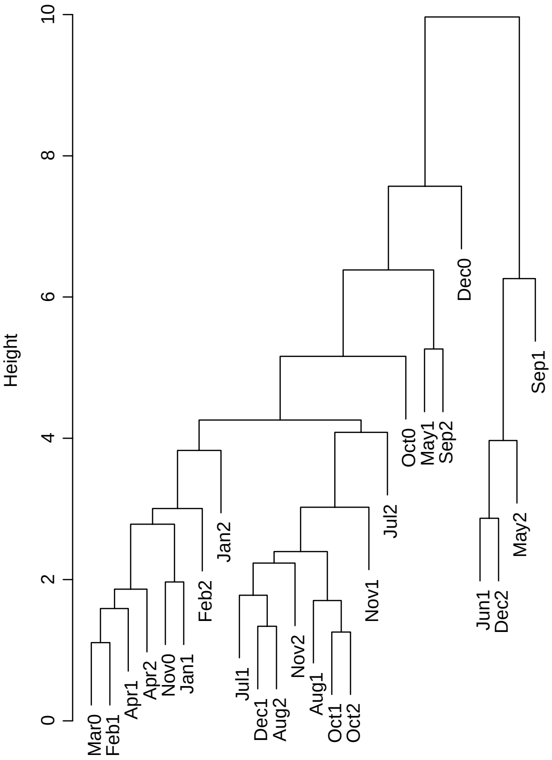
	Component											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Standard deviation	2.29	1.92	1.36	0.67	0.64	0.42	0.32	0.20	0.16	0.12	0.08	0.06
Proportion of Variance	0.44	0.31	0.15	0.04	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Cumulative Proportion	0.44	0.74	0.90	0.93	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00

Appendix 5

For each water quality variable, we provide dendrograms for sites and for month by year combinations. See Section 3.2.2 for some explanation about how to interpret the dendrograms.

DO%sat





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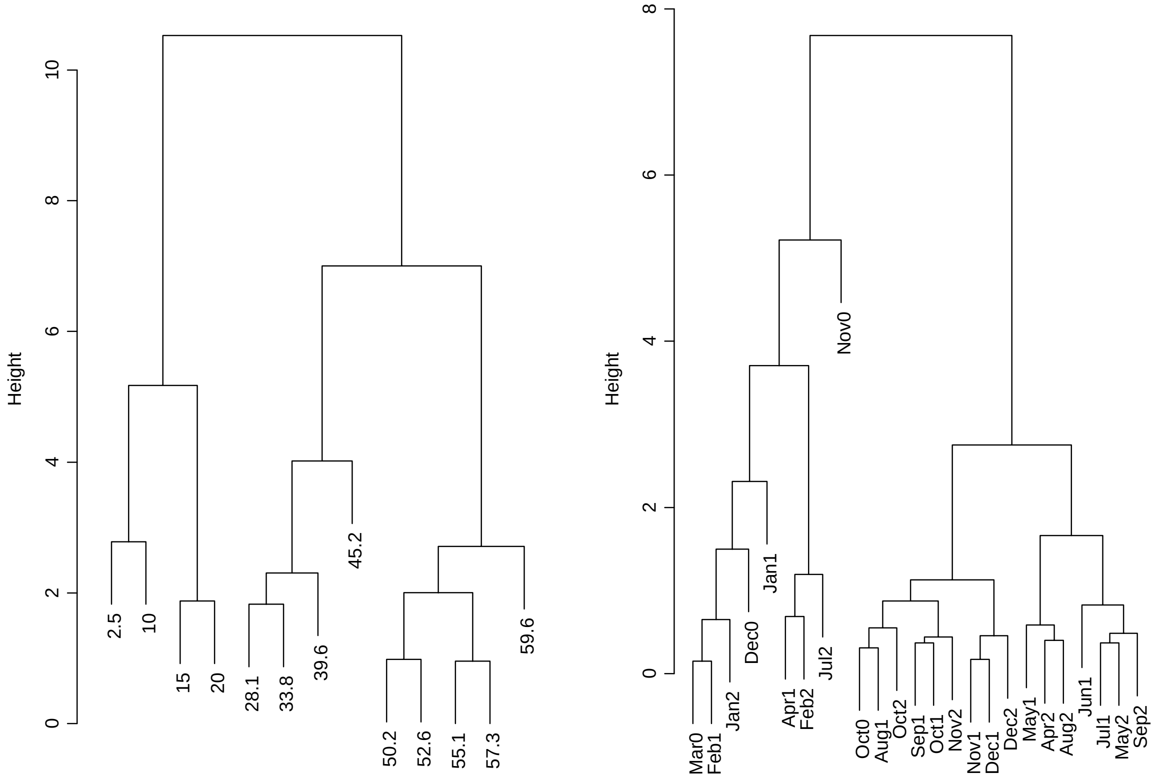
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52.6
55.1
57.3
59.6
Height
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4
6
8
Mar0
Feb1
Jan2
Dec0
Jan1
Apr1
Feb2
Jul2
Nov0
Oct0
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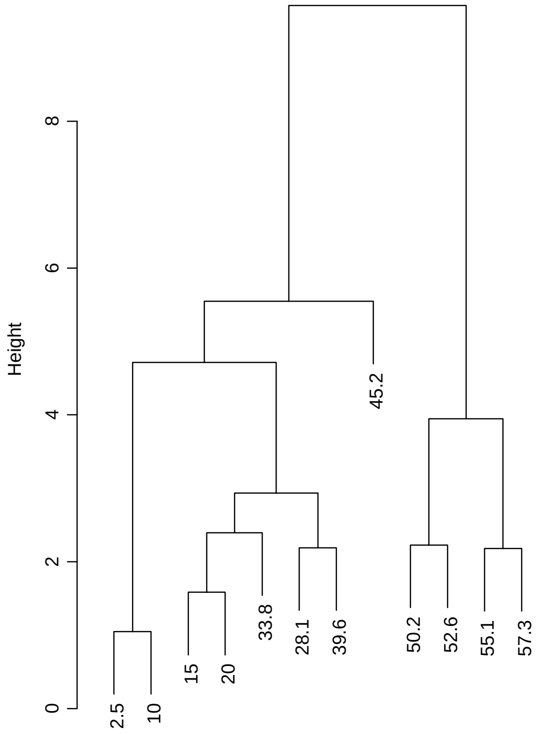
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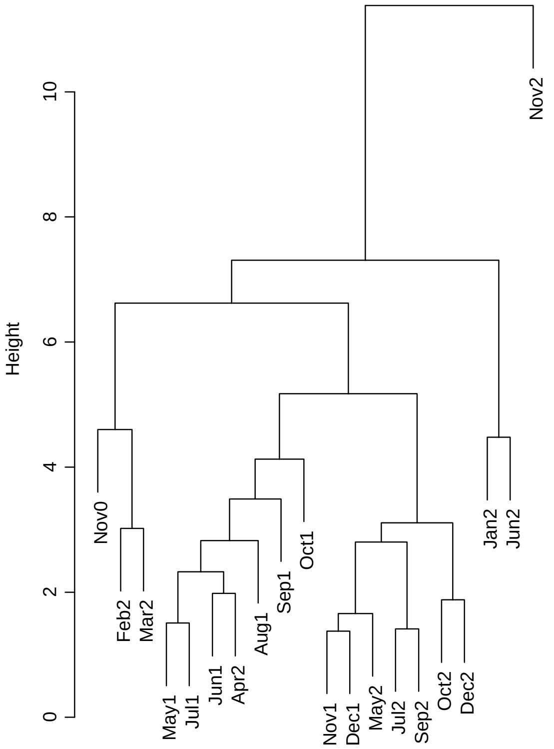
57.3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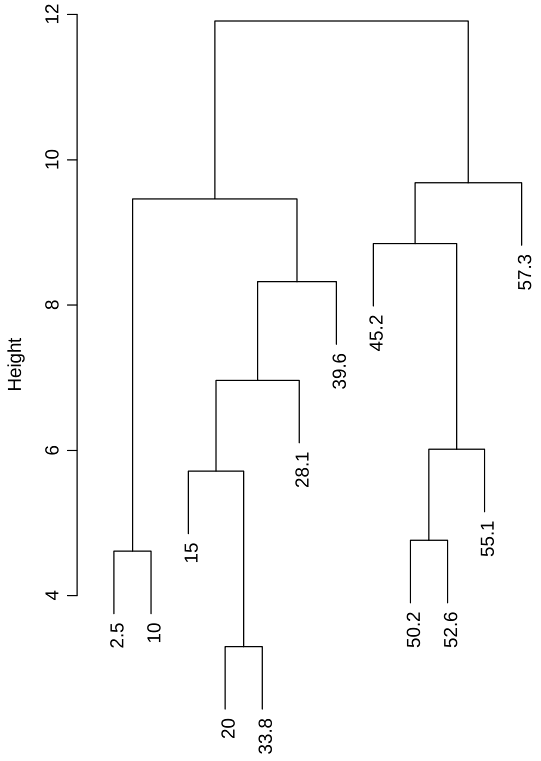
Jul2
Sep2
Oct2
Dec2
Jan2
Jun2
Nov2

log(NH4)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45.2
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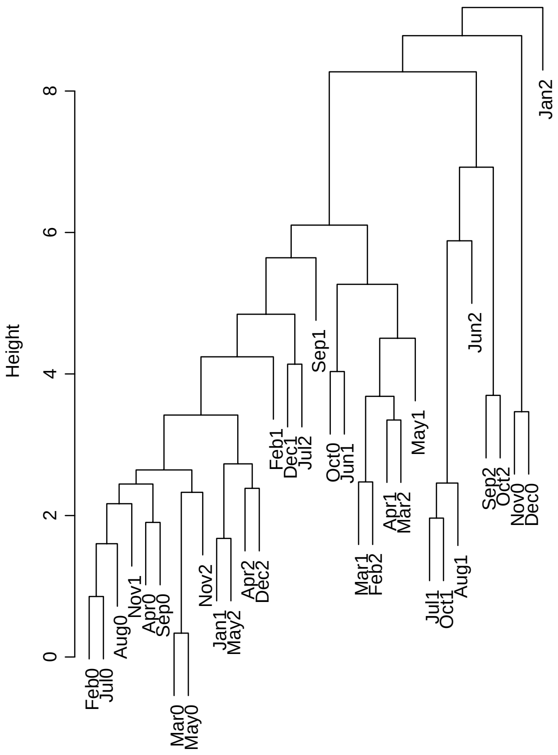
57.3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Sep1
Oct0
Jun1
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Sep2
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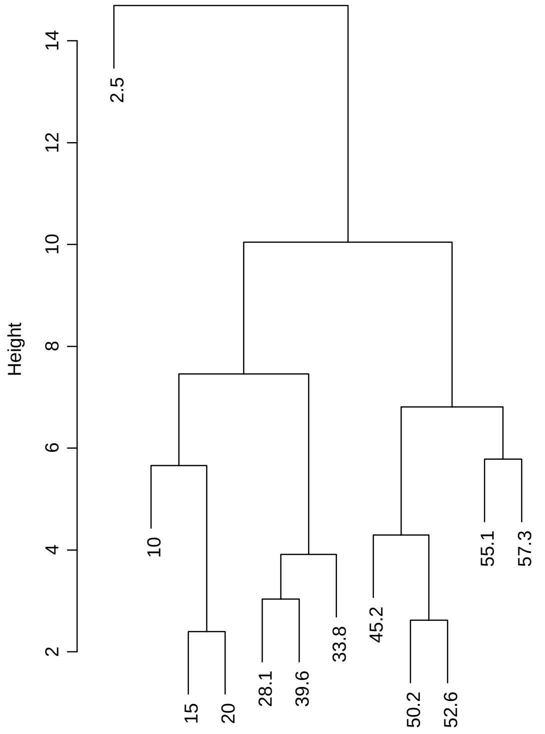
Dec0
Jan2

NOX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55.1
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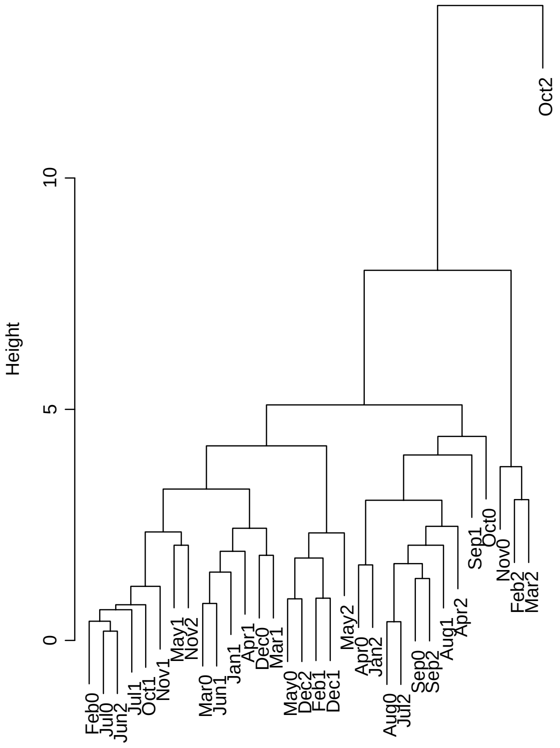
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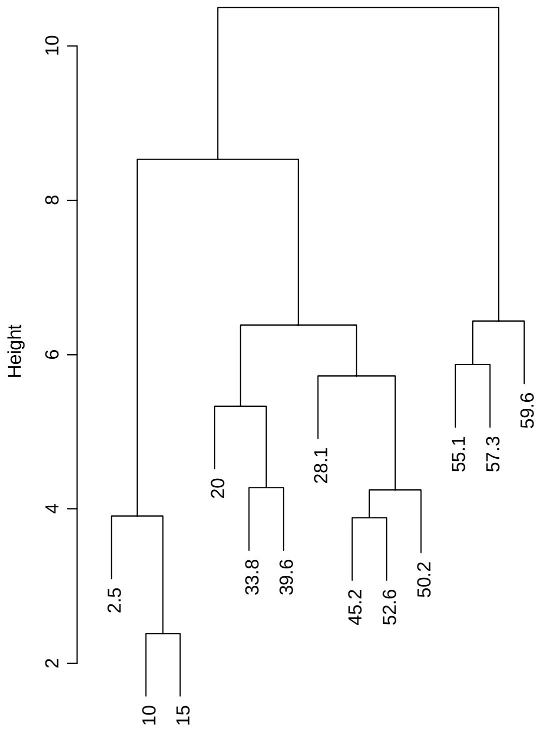
Feb2
Mar2
Oct2

Temp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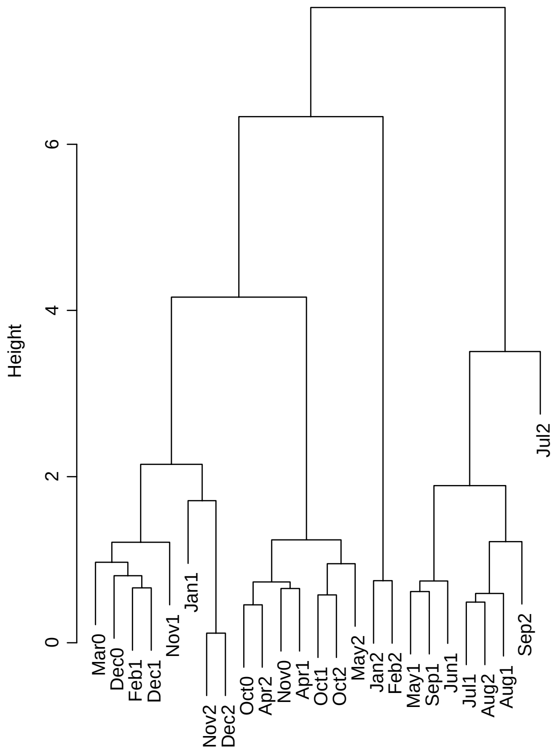
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May2
Jan2
Feb2
May1
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Jun1
Jul1
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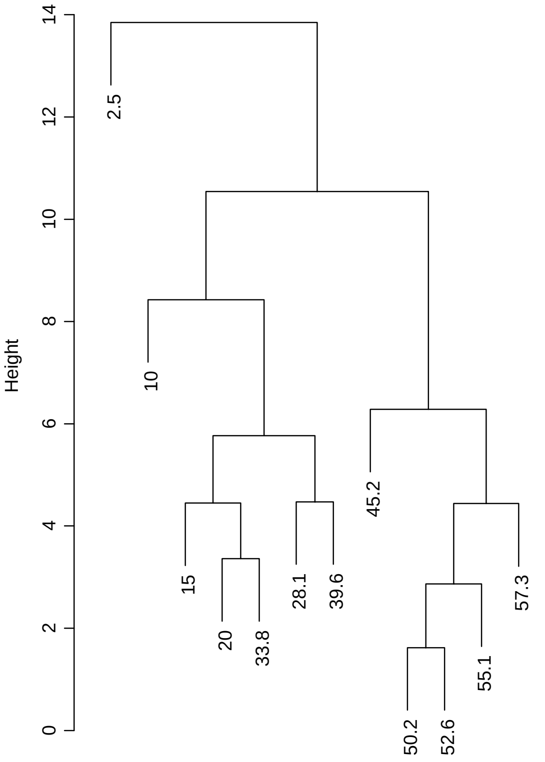
Aug1
Sep2
Jul2

TN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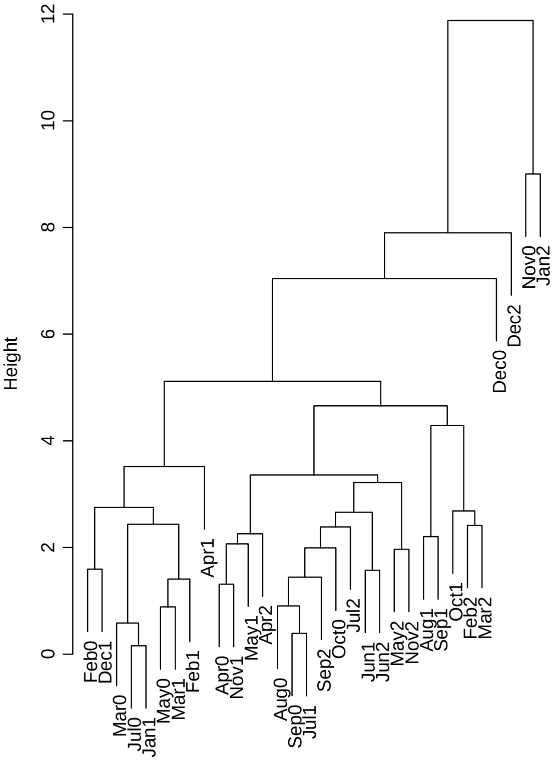
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Jul1
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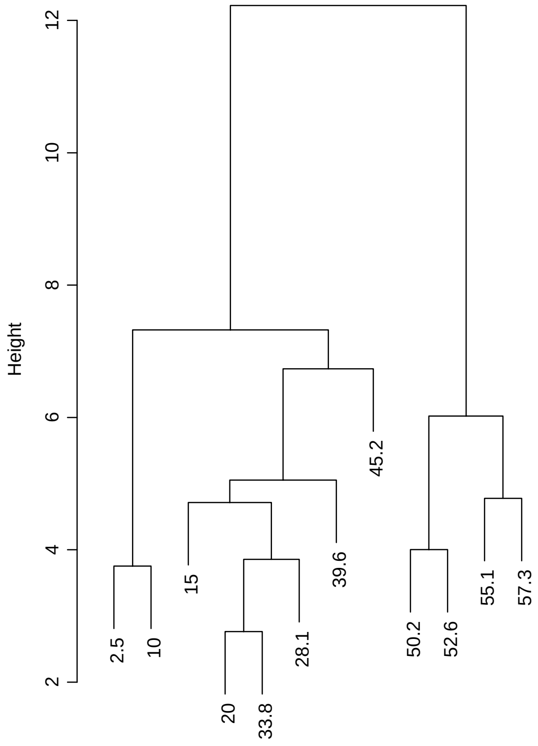
Nov0
Jan2

TP



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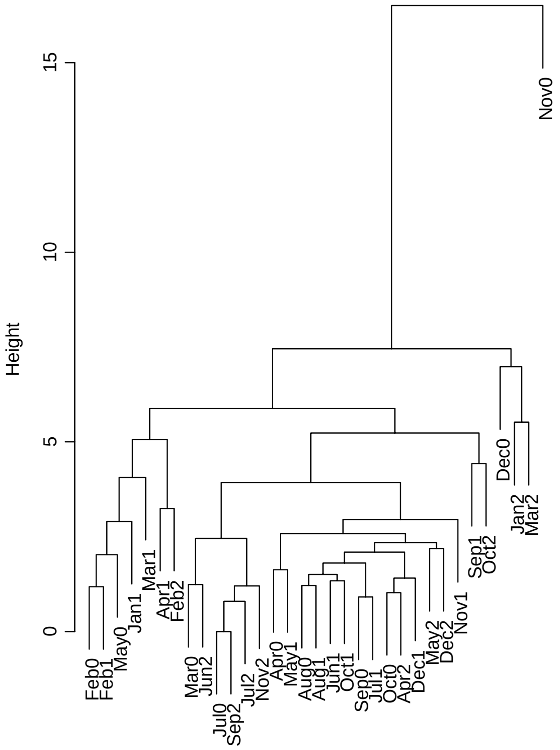

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Mar0
Jun2
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May1
Aug0
Aug1
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Dec0
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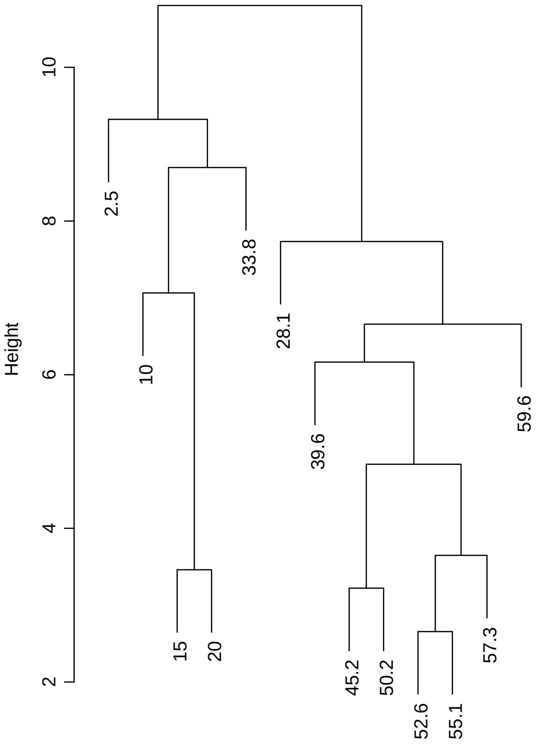
Nov0

log(Turb)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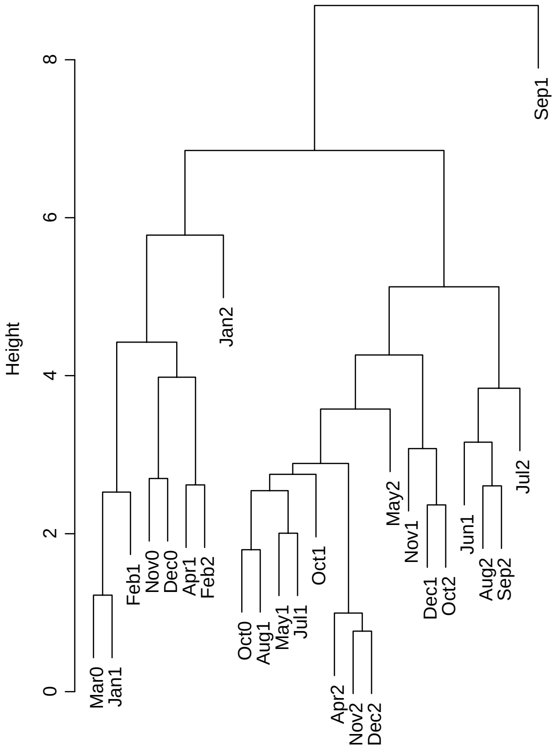
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