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Algal Blooms in Port Phillip Bay From March 1990 to February 1995: Temporal and Spatial Distribution and Dominant Species.

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EXECUTIVE SUMMARY

A study was conducted of the temporal and spatial distribution of algal blooms in Port Phillip Bay and of the species responsible for these blooms. Chlorophyll a and phytoplankton concentrations were determined from 876 and 884 samples respectively, collected from seven sites every fortnight between March 1990 and February 1995. Algal blooms were defined here as those water samples which contain a chlorophyll ***a*** concentration or total phytoplankton cell concentration greater than their respective 90% quantile values derived by pooling samples from the five year period.

Plots of the distribution of the 88 water samples with values greater than the 90% quantile values (2.86 μg L^{-1} for chlorophyll ***a*** and $1.4030\text{x}10^6$ cells L^{-1} for phytoplankton concentration) revealed considerable variation between sites, years and seasons. Spatially, the arithmetic mean concentration of chlorophyll ***a*** was highest at Werribee (1.99 μg L^{-1}) and Williamstown (1.93 μg L^{-1}), and the number of samples with values greater than the 90% quantile was also highest at these two sites (23 samples each). The highest arithmetic mean cell concentrations occurred at Williamstown ($1.31\text{x}10^6$ cells L^{-1}), Sandringham ($1.30\text{x}10^6$ cells L^{-1}) and Beaumaris ($1.05\text{x}10^6$ cells L^{-1}). The number of samples with cell concentrations greater than the 90% quantile was also highest at these three sites: Williamstown (29), Sandringham (13) and Beaumaris (20).

Mean species diversity (H') and species evenness (J') were clearly lowest in samples within the 90-100% quantile range for phytoplankton concentration. It appears that Bay algal blooms, as defined in this report, were mainly comprised of one or a few highly abundant species. Species richness was not reduced during blooms, although concentrations of the non-bloom species were relatively low.

Twenty-eight species or taxa, including twelve diatoms, were present in at least one 'algal bloom' sample, with a relative abundance greater than 10%. The diatom *Skeletonema costatum* was the most dominant species, occurring in 50 of the 88 most abundant samples. It comprised 99% of cell numbers in one sample from Beaumaris, and had a maximum concentration of $5.50\text{x}10^7$ cells L^{-1} at Sandringham in the summer of 1990. *Chaetoceros* spp., the second most frequently dominant species or taxa, occurred in 19 of the top 88 samples. A maximum concentration of $2.70\text{x}10^6$ cells L^{-1} (relative abundance 86%) was found at Wooley Reef in the spring of 1992.

Other dominants included the toxic dinoflagellate *Alexandrium catenella* (capable of causing paralytic shellfish poisoning), the potentially toxic diatom *Pseudonitzschia pseudodelicatissima* (the Port Phillip Bay strain apparently being non-toxic, although this species has caused amnesic shellfish poisoning overseas) and the nuisance diatom *Rhizosolenia* cf. *chunii* (which blooms in August/September and ruined the commercial mussel crops of 1987, 1993 and 1994 by causing the shellfish to develop an intense bitter taste). All other dominant species, including *S. costatum* and *Chaetoceros* spp., were beneficial and non-toxic.

Present results reveal that the current chlorophyll ***a*** standards (arithmetic means) specified in the existing 'State Environment Protection Policy' for Port Phillip Bay were exceeded at all seven sites in some years. Furthermore, new proposed standards (annual medians and 90% quantile values) in a draft revised policy issued for comment by the Environment Protection Authority (EPA) were also exceeded at four of the seven sites in either three or four of the five years. These findings, and the fact that toxic and nuisance phytoplankton blooms have already occurred in Port Phillip Bay over recent years, suggest that the proposed concentrations for chlorophyll ***a*** and present management strategies to minimise eutrophication both require re-examination.

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1. INTRODUCTION

Phytoplankton are a heterogeneous group of microscopic plants found in aquatic habitats. They are significant primary producers because they utilise solar energy, through photosynthesis, to supply energy for higher trophic levels such as zooplankton, fish and many benthic animals (Zeitzschel 1978). A greater understanding of phytoplankton communities and phytoplankton ecology is being made world-wide as a reflection of their importance in aquatic environments. Phytoplankton are routinely monitored in Port Phillip Bay (Arnott 1990) and in Tasmanian waters (HABTF 1994). Several components of the Port Phillip Bay Environmental Study investigated phytoplankton ecology in Port Phillip Bay (e.g. Wood and Beardall 1992, O'Leary *et al*. 1994, Beardall *et al.* 1996). The marine resources within Port Phillip Bay support recreational and commercial fisheries based on many shellfish and finfish species. Many of these species, such as scallops, mussels, pilchards and anchovy, feed directly on phytoplankton.

The distribution of marine phytoplankton is regulated by chemical, physical and biological conditions in the sea and consequently phytoplankton distribution is extremely patchy in time and space. Blooms of phytoplankton can occur under certain physical and biological conditions resulting in higher concentrations of algae. Algal blooms have been defined as "an outburst of the growth of phytoplankton ... which results in a high biomass of these organisms" (Richardson 1989, p. 83). Algal blooms produce an increased supply of food for other organisms, which can often result in a greater production of fish. However, blooms have also been associated with fish lesions and fish kills, bitter taste in shellfish (Parry *et al.* 1989), reduced settlement of shellfish larvae, and shellfish mortality and toxicity. Although blooms can occur from natural changes in the environment, an increase in the frequency and intensity of algal blooms in coastal regions usually occurs as a consequence of eutrophication (nutrient enrichment of the aquatic environment by man) (Richardson 1989).

Blooms are generally defined in a subjective manner, such as cell concentrations greater than usual or an increased concentration of chlorophyll ***a***. Thus the current 'State Environmental Protection Policy for Port Phillip Bay' recommends maximum chlorophyll ***a*** levels between 0.5 to 2 $\mu g\ L^{-1}$ for different segments of the Bay, the level varying among seasons for some of the segments (EPA 1975). Waste discharges are to be regulated to prevent increases in the mean concentration of chlorophyll ***a*** above these recommended levels.

Blooms may be species specific or result from an increase in the concentration of a number of species. The number of individual species present in each sample reflects the demography and dynamics of the community (Margalef 1978). Species diversity indices describe how the species in each sample were distributed within the community and allow comparison of diversity among samples. The Shannon-Weaver diversity index (H') and two components of diversity, species richness (SR) and species evenness (J'), were used to investigate species dominance during algal blooms in this study. These indices are widely used in comparisons of phytoplankton species diversity (Margalef 1978, Magurran 1988, Siqueiros Beltrones 1990).

There have been a number of toxic or nuisance algal blooms in Port Phillip Bay over the last eight years (Arnott, unpublished data). The toxic dinoflagellate *Alexandrium catenella* has occurred in the Hobsons Bay region of Port Phillip Bay in varying concentrations during summer and/or autumn of every year since January 1988. Port Phillip Bay populations of this species, and of the related toxic species *Alexandrium tamarense* which bloomed in July-August 1993 in the Geelong Arm, have both produced toxins capable of causing paralytic shellfish poisoning (PSP). These toxins are very potent and have resulted in many deaths overseas, but not in Australia. Public health alerts and suspensions of commercial shellfish harvesting have occurred as a result of these blooms.

A bloom of the diatom *Rhizosolenia* cf. *chunii* in August-September 1987 caused an intense bitter taste to develop in mussels (*Mytilus galloprovincialis*), scallops (*Pecten fumatus*) and flat oysters (*Ostrea angasi*) rendering the mussels and oysters unmarketable (Parry *et al.* 1989). Further blooms of *Rhizosolenia* cf. *chunii* occurred in August-September of 1993 and 1994 with similar adverse results. Another potentially toxic species, the diatom *Pseudonitzschia pseudodelicatissima*, bloomed throughout Port Phillip Bay from October 1991 to February 1992 and has re-appeared several times since. Overseas populations of this species have produced domoic acid, the toxin responsible for amnesic shellfish poisoning (ASP), and three deaths occurred in Canada in 1987. No domoic acid has been detected to date in Port Phillip Bay populations of *P. pseudodelicatissima* or in Bay shellfish.

The objective of this study was to determine the temporal and spatial distribution of algal blooms in Port Phillip Bay, and to determine the species responsible for these blooms. A quantitative definition of algal blooms was used in this investigation. Algal blooms are characterised by water samples which contain a chlorophyll ***a*** concentration or total phytoplankton cell concentration greater than their respective 90% quantile values calculated from a large dataset. The quantile values were derived, in the present case, from five years of sampling from March 1990 to February 1995. The plant pigment chlorophyll ***a*** was chosen as one parameter as it is an important indicator of phytoplankton biomass.

The distribution of samples with cell concentrations of diatoms and dinoflagellates greater than their respective 90% quantile values was also examined, to investigate blooms of these two important classes of phytoplankton. Diatoms and dinoflagellates are important because they are dominant groups in the phytoplankton represented by many species, because they exist at the base of the food chain and provide food for many other marine organisms, and because we need to better understand the population dynamics of the few potentially harmful and nuisance species mentioned above. Our definition of algal blooms has the advantage of being specific to the particular locality under consideration, and enables the distribution of algal blooms to be readily examined. Data for this study was obtained from the Port Phillip Bay Phytoplankton Database maintained by the Marine and Freshwater Resources Institute (MAFRI) at Queenscliff (Magro and Arnott, in press).

2. METHODS

2.1. The Port Phillip Bay Phytoplankton Database

Phytoplankton monitoring in Port Phillip Bay has been conducted by the Marine and Freshwater Resources Institute since September 1987 and is still in progress. A one litre (1 L) sample of surface water is collected at each site to enable cell concentrations to be estimated. Additional physico-chemical data are collected, as well as a 1.5 L surface water sample for determining chlorophyll concentration by filtration and extraction. Phytoplankton identifications and cell counts are performed under the supervision of Dr David Hill of the School of Botany, University of Melbourne.

The water samples are concentrated by continuous centrifugation to a final volume of about 7 mL. Cell counts are conducted using a haemocytometer with a chamber volume of 0.9 mm^3 (3mm x 3mm x 0.1mm). At least 100 cells of the most abundant species are counted; this number meets the statistical requirements recommended in the literature (see review by Venrick 1978). However, additional grids are examined to count the cells of less abundant species. Cell counts are then extrapolated to provide cell concentrations in the original one litre water sample. Species identifications are made with the aid of a light microscope and periodically verified using an electron microscope. Data are recorded onto phytoplankton report sheets and entered into the phytoplankton database at MAFRI. Details of data entry, operation and maintenance of the phytoplankton database are given in Magro and Arnott (in press).

The data examined for this report were from a five-year period of intensive fortnightly sampling between March 1990 and February 1995. During this time, cell concentrations of phytoplankton species were determined for Blairgowrie, Wooley Reef, Beaumaris, Sandringham, Williamstown, Werribee and Clifton Springs (Figure 1). The seven sites were sampled on the same day wherever possible, although some cruises extended over several days. In these instances the first sampling date defines the date of the particular cruise. Either 26 or 27 cruises were conducted in any one year, and a total of 131 cruises were conducted between March 1990 and February 1995 (Table 1). Although it was intended to sample all seven sites during each cruise, on some cruises less than seven sites were sampled (Table 2). The mean number of sites sampled during a cruise was 6.75. The data available for each site from each cruise included chlorophyll ***a***, phytoplankton species composition and concentrations, and species diversity. These variables are described in greater detail below.

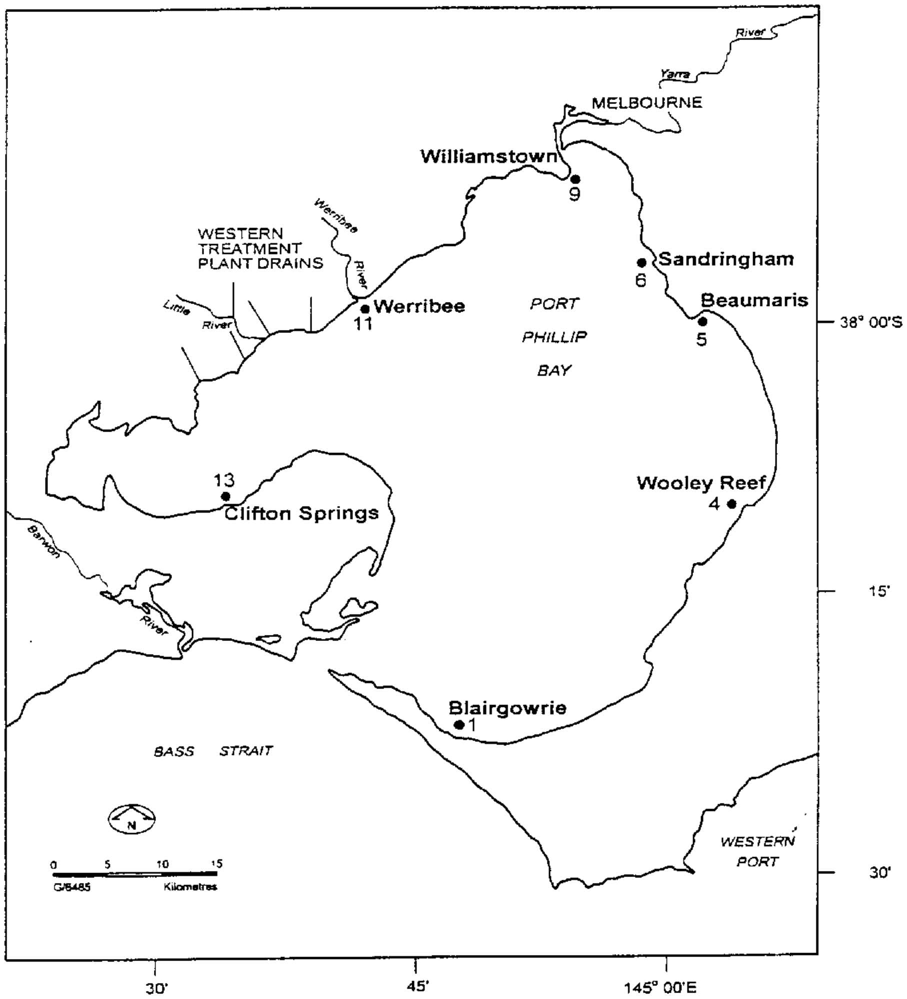

Figure 1: Map of Port Phillip Bay showing the locations of sites where phytoplankton samples were collected fortnightly from March 1990 to February 1995.

Table 1: The number of sampling cruises (for phytoplankton and chlorophyll a) for each month between March 1990 and February 1995.

Month	1990	1991	1992	1993	1994	Total
March	2	2	3	3	3	**13**
April	2	2	2	2	1	**9**
May	3	3	2	2	2	**12**
June	2	2	2	2	3	**11**
July	2	2	2	2	2	**10**
August	2	2	2	3	3	**12**
September	2	2	2	2	2	**10**
October	3	3	3	2	2	**13**
November	2	2	2	2	2	**10**
December	2	2	2	2	2	**10**
January	2	2	2	3	3	**12**
February	2	2	2	2	1	**9**
Total	**26**	**26**	**26**	**27**	**26**	**131**

Table 2: Frequency of cruises for the number of sites sampled during each cruise and the calculated total number of phytoplankton samples collected.

Number of sites	Frequency of cruises	Number of samples
7	115	805
6	8	48
5	3	15
4	2	8
3	2	6
2	1	2
Total	**131**	**884**

2.2. Variables Investigated Relevant To Phytoplankton Blooms

Chlorophyll a

Chlorophyll ***a*** data for each sample were determined at the Chemistry Services Section of MAFRI. Additional chlorophyll ***a*** data from Program 700 (Longmore *et al.* 1994) were used to supplement the chlorophyll ***a*** data collected for this study. Chlorophyll ***a*** concentrations were measured in µg L^{-1}.

Phytoplankton Concentration

The March 1990 to February 1995 subset of the Port Phillip Bay Phytoplankton Database included 205 phytoplankton species or taxa with a total of 12,057 records of phytoplankton cell concentration (Table 3). The number of records for each year and total number for each month over the five-year period are also shown in Table 3.

The Diatomophyceae and Dinophyceae had by far the most representatives with 76 and 52 species or taxa respectively. "Unidentified picoplankters" (cells < 2 µm) were removed from the dataset as they had not been enumerated consistently throughout the period of study. However, some picoplankters (e.g. the dominant taxa *Plagioselmis prolonga* and *Chrysochromulina* spp.) were more easily identifiable under a light microscope and were systematically treated; these taxa have been included.

Table 3: The number of records for cell concentration of all phytoplankton species for each year and the total number for each month over the five-year period.

Month	1990	1991	1992	1993	1994	Total
Mar	144	254	266	280	380	**1324**
Apr	236	228	153	200	96	**913**
May	427	338	132	207	196	**1300**
Jun	217	234	151	153	180	**935**
Jul	276	151	140	184	89	**840**
Aug	229	149	140	279	172	**969**
Sep	191	168	153	159	111	**782**
Oct	398	269	228	244	138	**1277**
Nov	248	206	136	226	152	**968**
Dec	117	202	220	256	136	**931**
Jan	132	163	157	155	252	**859**
Feb	224	197	201	253	84	**959**
Total	**2839**	**2559**	**2077**	**2596**	**1986**	**12057**

Species Diversity

Species diversity, and two components of diversity, were examined to characterise the top 10% of phytoplankton samples according to total cell concentration, and to compare these results with those for other sample groups falling within other quantile ranges.

The commonly used Shannon-Weaver diversity index (H’) was calculated for each sample. This index compares the proportion of individual species (p_i) in a sample as shown in Equation 1 (Shannon and Weaver 1949).

Equation 1: $$H' = -\sum_{i=1}^{s} p_i \log_2 p_i$$

Species richness, the number of species recorded in a sample during sample analysis, was the first component of diversity.

The second component was species evenness (J’), which indicates the spread of individuals among the species. This index was calculated using a modification of the Shannon-Weaver Index (see Equation 2; Pielou 1969).

Equation 2: $$J' = \frac{H'}{H'_{max}}$$

The most diverse samples, according to this index, are those in which individuals are most evenly spread among all the species in a sample. The maximum number of species in a sample (H'_{max}), describing the distribution that is perfectly even, was determined from the log of the total number of species from all samples (s) (see Equation 3).

Equation 3: $$H'_{max} = \log_{10} s$$

2.3. Data Analyses

The five year subset of data between March 1990 and February 1995 from the Port Phillip Bay Phytoplankton Database has a possible maximum of 917 samples (7 sites and 131 cruises). Summary statistics for each cruise and site included concentration of chlorophyll ***a***; total cell concentrations for all phytoplankton combined, diatoms and dinoflagellates; and the Shannon-Weaver (H’), species richness (SR) and species evenness (J’) indices. The data was unbalanced because of missing samples (due to omission of three outliers and because not all sites were sampled during some cruises).

The number of species appeared exceptionally low in several samples. Removal of these outliers was achieved objectively by eliminating samples where the total number of species was less than 4 (the 1 % quantile value) and the total cell concentration was less than 8.6×10^4 cells L^{-1} (the 1 % quantile value). A further qualification for removal was applied, i.e. that additional species had to be present in a corresponding net tow for an outlier sample, indicating the likelihood of other species for which cell concentrations should have been determined. This procedure resulted in the exclusion of three phytoplankton samples (Werribee on 23 January 1991, Williamstown on 16 September 1993 and Beaumaris on 1 June 1994).

Incomplete cruises were retained for analysis because omission of sites was the result of random events such as sudden unsafe weather conditions or problems with vessels. Random events were unlikely to bias the data and most analyses were robust to some degree of missing data. A total of 884 phytoplankton samples were taken during the 131 cruises (Table 2), while 876 chlorophyll ***a*** samples were obtained during the same five year period.

Cruises were allocated into annual and seasonal time components. A nominal year extended from March to February of the following calendar year. Autumn and summer were therefore the first and last season respectively in each year. This allowed each year to be divided into the four complete seasons. The number of cruises in each season ranged between six and eight (mean 6.55).

The data variables chlorophyll ***a***, and cell concentration of all phytoplankton species, diatoms and dinoflagellates were displayed at fine and broad spatial and temporal scales. Values were placed into 75 to 90%, 90 to 95% and 95 to 100 % quantile groupings for presentation of the whole dataset. This display allowed spatial and temporal patterns to be more easily observed. Time series plots of individual values of these same variables were prepared for each site.

Cell concentrations of individual species were examined for samples where the total cell concentration was greater than the 90 % quantile value (1.4030×10^6 cells L^{-1}), in order to assess which species were dominant during times of algal blooms. The relative abundance of each species in these samples was calculated, and species contributing 10% or more were listed. A second approach was also undertaken to assess dominance. The mean cell concentration and relative abundance of dominant species within each year and season were calculated, again using samples with total cell concentrations greater than the 90% quantile value derived from the five year dataset.

3. RESULTS

3.1. Chlorophyll *a*

An examination of the time distribution of chlorophyll ***a*** for all seven sites (Figure 2) showed that some sites were much more variable than others. Concentrations were low and quite constant at Blairgowrie, relatively low and constant with only a few concentration spikes at Clifton Springs, somewhat higher and more variable with a greater number of concentration peaks at Wooley Reef, Beaumaris and Sandringham and highest and most variable with considerably more concentrations greater than the 90% quantile value of 2.86 μg L^{-1} at Williamstown and Werribee (see also arithmetic means and standard errors in Table 4). Also evident is the reduced concentration at most sites except Williamstown and Werribee (the sites nearest to major freshwater inputs) in 1994. The highest concentration of chlorophyll ***a*** (19.7 μg L^{-1}) was recorded at Williamstown on 7 January 1992 when the toxic dinoflagellate *Alexandrium catenella* rapidly bloomed following very heavy rainfall.

The annual mean chlorophyll ***a*** concentration was highest in 1990 and 1992 at 1.66 and 1.74 μg L^{-1} respectively, with lower annual mean concentrations of chlorophyll ***a*** in 1991, 1993 and 1994 at 1.47, 1.45 and 1.07 μg L^{-1} respectively (Table 4). These differences were consistent with the number of samples in a given year with chlorophyll ***a*** values greater than the 90% quantile calculated from the five year dataset (Figure 3, Table 4). There were 25 and 23 samples with chlorophyll ***a*** concentrations greater than 2.86 μg L^{-1} in 1992 and 1990 respectively. However, only 15 and 18 samples had concentrations above the 90% quantile in 1991 and 1993, and only seven samples in 1994.

The mean seasonal concentration of chlorophyll ***a*** (averaged over five years data) was 1.41 μg L^{-1} in autumn and decreased to a winter minimum of 1.28 μg L^{-1} (Table 4). The mean seasonal concentration of chlorophyll ***a*** increased in spring to 1.54 μg L^{-1} and was highest during summer at 1.67 μg L^{-1}. On a seasonal basis there were 27 and 30 samples with values greater than the 90% quantile (2.86 μg L^{-1}) in spring and summer respectively (Figure 3, Table 4), while autumn and winter had 15 and 16 samples respectively above the 90% quantile value.

The sites with the highest mean concentration of chlorophyll ***a*** were Werribee (1.99 μg L^{-1}) and Williamstown (1.93 μg L^{-1}) (Table 4). Concentrations at other sites in Port Phillip Bay were 1.72 at Beaumaris, 1.50 at Sandringham, 1.34 at Wooley Reef, 1.18 at Clifton Springs and 0.69 μg L^{-1} at Blairgowrie. These spatial differences among sites were reflected in the number of samples with chlorophyll ***a*** concentrations greater than 2.86 μg L^{-1} (the 90% quantile), i.e. 23 samples each from Werribee and Williamstown, 12 samples each from Beaumaris and Wooley Reef, 11 samples from Sandringham and seven samples from Clifton Springs (Figure 3, Table 4). There were no samples with chlorophyll ***a*** concentrations greater than the 90% quantile, or even greater than the 75% quantile, from Blairgowrie.

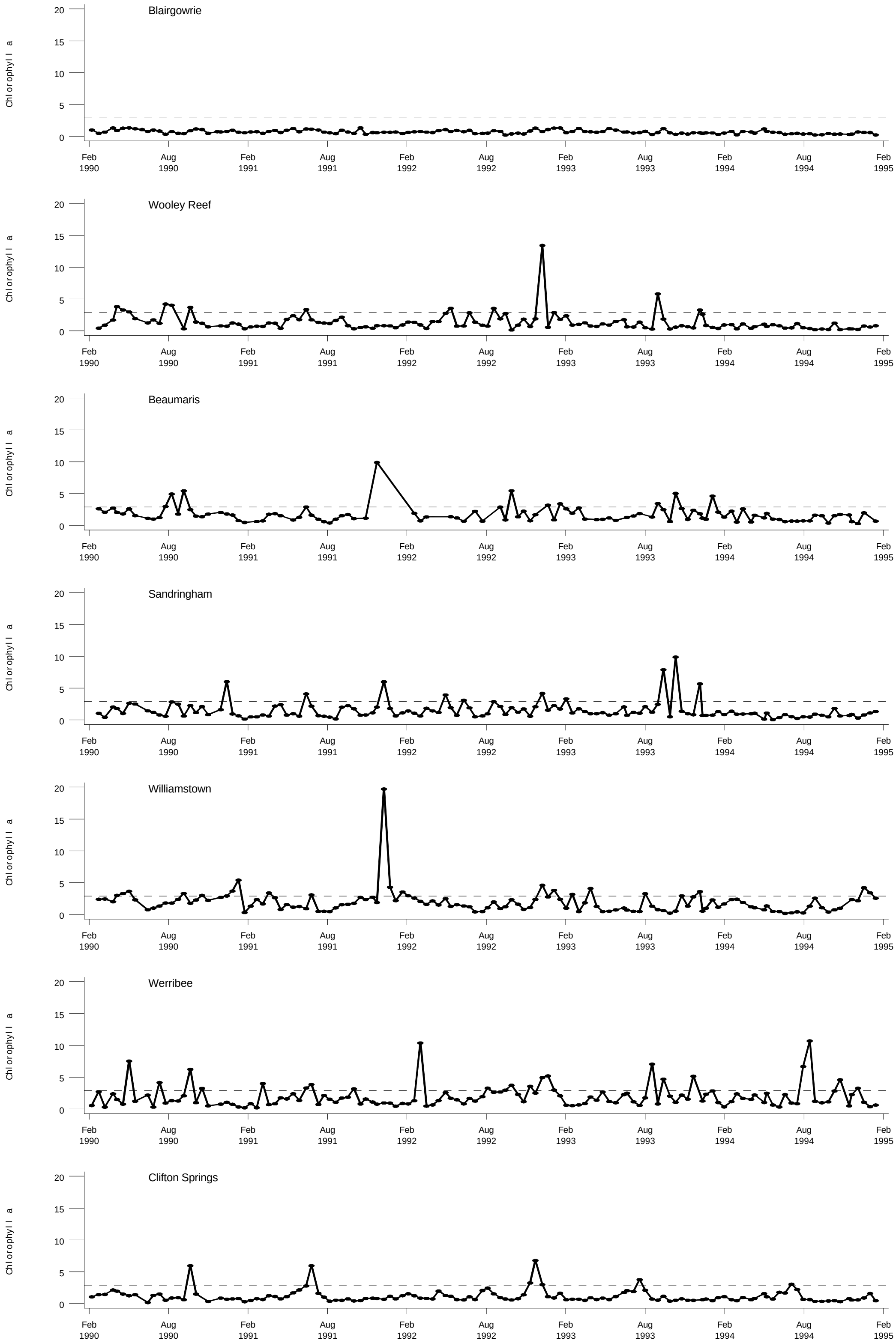

Figure 2: Time distribution of chlorophyll *a* concentration (μg L^{-1}) for each site. The dashed line indicates the 90 percentage quantile (2.86 μg L^{-1}) over all site and time combinations. The x-axis labels indicate the end of the specified month.

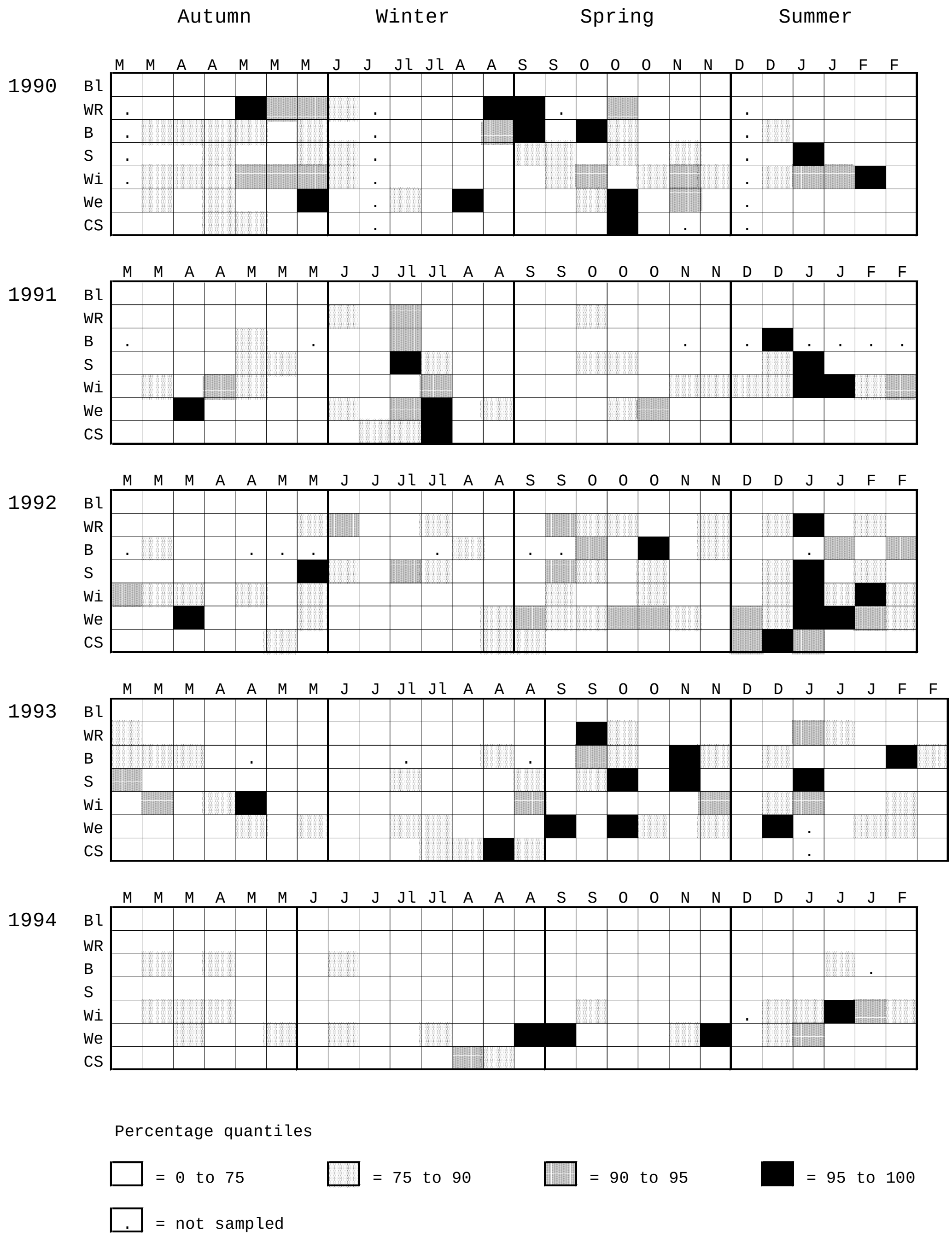

Figure 3: Summary of percentage quantiles for chlorophyll *a* concentration (µg L^{-1}) for individual sites and cruises.

Table 4: Summary of chlorophyll a (µg L^{-1}) values corresponding to percentile ranges, number of samples in percentage quantiles and descriptive statistics.

Percentile range	Range of values	Number of samples
0 to 75	0.05 to 1.83	657
>75 to 90	1.83 to 2.86	131
>90 to 95	2.86 to 3.75	44
>95 to 100	3.75 to 19.70	44
Total		**876**

	n	Arithmetic Mean	se	90 to 95 %	95 to 100 %	Total (> 90 %)
1990	164	1.66	0.10	12	11	23
1991	174	1.47	0.14	7	8	15
1992	174	1.74	0.12	15	10	25
1993	184	1.45	0.10	7	11	18
1994	180	1.07	0.08	3	4	7
Autumn	227	1.41	0.07	9	6	15
Winter	222	1.28	0.06	9	7	16
Spring	226	1.54	0.10	13	14	27
Summer	201	1.67	0.15	13	17	30
Blairgowrie	131	0.69	0.03	0	0	0
Wooley Reef	127	1.34	0.13	7	5	12
Beaumaris	108	1.72	0.13	6	6	12
Sandringham	128	1.50	0.13	3	8	11
Williamstown	127	1.93	0.17	16	7	23
Werribee	128	1.99	0.16	9	14	23
Clifton Springs	127	1.18	0.09	3	4	7
Total				**44**	**44**	**88**

As draft guidelines for maximum permitted concentrations of chlorophyll a have been proposed for different segments of Port Phillip Bay based on annual median values and annual 90% quantiles (EPA 1995), the annual arithmetic mean, standard error, median and 90% quantile for chlorophyll a for each site is provided in Table 5. These results are considered later in the discussion.

Table 5: Annual arithmetic mean, standard error, median and 90% quantile for chlorophyll a (µg L^{-1}) for all sites. Total values were calculated after pooling data from the five year period for each site.

Site	Sitecode	Year	n	Mean (µg L^{-1})	se	Median	90% quantile
Blairgowrie	1	1990	26	0.83	0.06	0.80	1.28
		1991	26	0.74	0.05	0.68	1.15
		1992	26	0.75	0.06	0.75	1.29
		1993	27	0.65	0.05	0.59	1.20
		1994	26	0.50	0.04	0.45	0.79
		Total	131	0.69	0.03	0.66	1.15
Wooley Reef	4	1990	22	1.76	0.27	1.24	3.79
		1991	26	1.15	0.14	0.87	2.15
		1992	26	2.03	0.49	1.42	3.52
		1993	27	1.25	0.23	0.83	2.61
		1994	26	0.61	0.06	0.54	1.08
		Total	127	1.34	0.13	0.92	2.86
Beaumaris	5	1990	23	2.06	0.24	1.79	2.96
		1991	18	1.73	0.50	1.20	2.89
		1992	18	1.81	0.30	1.36	3.39
		1993	24	1.92	0.24	1.65	3.44
		1994	25	1.16	0.13	0.99	1.97
		Total	108	1.72	0.13	1.49	2.89
Sandringham	6	1990	23	1.61	0.26	1.19	2.61
		1991	26	1.45	0.25	0.88	2.40
		1992	26	1.70	0.19	1.62	3.09
		1993	27	1.99	0.44	1.14	5.67
		1994	26	0.76	0.08	0.81	1.33
		Total	128	1.50	0.13	1.06	2.61
Williamstown	9	1990	23	2.42	0.23	2.38	3.63
		1991	26	2.56	0.71	1.71	3.53
		1992	26	1.86	0.19	1.60	2.94
		1993	27	1.42	0.22	0.99	3.26
		1994	25	1.46	0.21	1.21	2.56
		Total	127	1.93	0.17	1.61	3.38
Werribee	11	1990	24	1.80	0.38	1.14	4.15
		1991	26	1.55	0.20	1.22	3.29
		1992	26	2.55	0.39	2.18	4.93
		1993	26	1.96	0.30	1.47	4.70
		1994	26	2.08	0.45	1.18	4.60
		Total	128	1.99	0.16	1.42	4.01
Clifton Springs	13	1990	23	1.27	0.24	1.05	1.95
		1991	26	1.17	0.22	0.80	2.14
		1992	26	1.52	0.25	1.12	2.98
		1993	26	1.00	0.15	0.70	2.03
		1994	26	0.94	0.13	0.68	1.77
		Total	127	1.18	0.09	0.86	2.08

Although higher concentrations of chlorophyll ***a*** occurred overall during spring and summer, this was not true for all sites (Figure 3 and Table 6). Seasonal mean concentrations at Blairgowrie, for example, were greater during autumn and winter than during spring and summer. During spring the mean concentration of chlorophyll ***a*** for Werribee (2.59 µg L^{-1}) was considerably higher than that for all other sites. There were ten samples with concentrations greater than the 90% quantile for Werribee in spring, compared with five or fewer for the remaining sites. During summer the highest mean concentration of chlorophyll ***a*** (3.22 µg L^{-1}) was recorded for Williamstown; this value was markedly higher than the summer means for the remaining sites. There were 11 samples with values greater than the 90% quantile for Williamstown in summer, compared with six from Werribee, four from both Beaumaris and Sandringham, three and two from Clifton Springs and Wooley Reef respectively, and none from Blairgowrie.

Table 6: Seasonal arithmetic mean, standard error and number of samples above the 90% quantile for concentration of chlorophyll *a* (µg L^{-1}) for all sites. The 90% quantile (2.86 µg L^{-1}) was calculated from all time and site combinations.

Site	Site code	Season	n	Mean (µg L^{-1})	se	Samples above 90% quantile
Blairgowrie	1	Autumn	34	0.77	0.04	0
		Winter	33	0.77	0.05	0
		Spring	33	0.57	0.05	0
		Summer	31	0.66	0.05	0
		Total	131	0.69	0.03	0
Wooley Reef	4	Autumn	33	1.27	0.15	3
		Winter	32	1.42	0.17	3
		Spring	32	1.32	0.24	4
		Summer	30	1.38	0.44	2
		Total	127	1.34	0.13	12
Beaumaris	5	Autumn	26	1.65	0.15	0
		Winter	29	1.25	0.12	2
		Spring	30	2.05	0.26	5
		Summer	23	1.97	0.42	4
		Total	108	1.72	0.13	11
Sandringham	6	Autumn	33	1.35	0.14	2
		Winter	32	1.15	0.16	2
		Spring	33	1.83	0.35	3
		Summer	30	1.68	0.30	4
		Total	128	1.50	0.13	11
Williamstown	9	Autumn	33	2.07	0.16	7
		Winter	32	1.00	0.13	2
		Spring	33	1.56	0.15	3
		Summer	29	3.22	0.63	11
		Total	127	1.93	0.17	23
Werribee	11	Autumn	34	1.80	0.35	3
		Winter	32	1.78	0.23	4
		Spring	33	2.59	0.37	10
		Summer	29	1.78	0.27	6
		Total	128	1.99	0.16	23
Clifton Springs	13	Autumn	34	1.02	0.07	0
		Winter	32	1.63	0.20	3
		Spring	32	0.90	0.18	1
		Summer	29	1.17	0.23	3
		Total	127	1.18	0.09	7

3.2. Phytoplankton Concentration

Total Phytoplankton Cell Concentrations

The time distribution of total cell concentration for all phytoplankton species combined was considerably more variable than the variation in chlorophyll ***a*** at the seven sites (Figure 4). Cell concentrations were lowest and least variable at Blairgowrie and Clifton Springs, while values for Werribee were also not particularly variable. Concentrations were most variable at Williamstown and Sandringham.

The annual mean cell concentration for total phytoplankton was highest in 1990 with 1.42×10^6 cells L^{-1}. Slightly lower annual mean cell concentrations were observed in 1991 (8.05×10^5 cells L^{-1}), 1993 (8.05×10^5), 1992 (7.28×10^5) and 1994 (6.4×10^5). The number of samples with values greater than the 90% quantile (1.40×10^6 cells L^{-1}) was highest in 1990 and 1991 with 23 and 21 samples respectively (Figure 5, Table 7). There were fewer samples with values above the 90% quantile in 1993 (17 samples) and 1992 (16 samples), and considerably fewer in 1994 (11 samples).

Table 7: Summary of total cell concentrations (cells L^{-1}) of all phytoplankton species combined: values corresponding to percentile ranges, number of samples in percentage quantiles and descriptive statistics.

Percentile range	Range of values	Number of samples
0 to 75	4.3200×10^4 to 7.6350×10^5	663
>75 to 90	7.6350×10^5 to 1.4030×10^6	133
>90 to 95	1.4030×10^6 to 2.3100×10^6	44
>95 to 100	2.3100×10^6 to 5.5570×10^7	44
Total		**884**

	n	Arithmetic Mean	se	90 to 95 %	95 to 100 %	Total (> 90 %)
1990	169	1.4161×10^6	3.7888×10^5	9	14	23
1991	174	8.0472×10^5	8.2534×10^4	10	11	21
1992	182	7.2754×10^5	1.0849×10^5	8	8	16
1993	179	8.0526×10^5	9.2125×10^4	9	8	17
1994	180	6.3638×10^5	1.3507×10^5	8	3	11
Autumn	235	7.2971×10^5	1.0478×10^5	10	8	18
Winter	216	4.7574×10^5	2.2267×10^4	4	0	4
Spring	228	8.3096×10^5	1.3458×10^5	11	11	22
Summer	205	1.4963×10^6	3.0574×10^5	19	25	44
Blairgowrie	128	4.2012×10^5	2.7315×10^4	3	0	3
Wooley Reef	125	7.3424×10^5	1.3228×10^5	6	3	9
Beaumaris	130	1.0506×10^6	3.8424×10^5	9	11	20
Sandringham	129	1.3006×10^6	4.4676×10^5	5	8	13
Williamstown	127	1.3086×10^6	2.7968×10^5	11	13	24
Werribee	121	7.4008×10^5	6.8347×10^4	5	7	12
Clifton Springs	124	5.2259×10^5	4.1718×10^4	5	2	7
Total				**44**	**44**	**88**

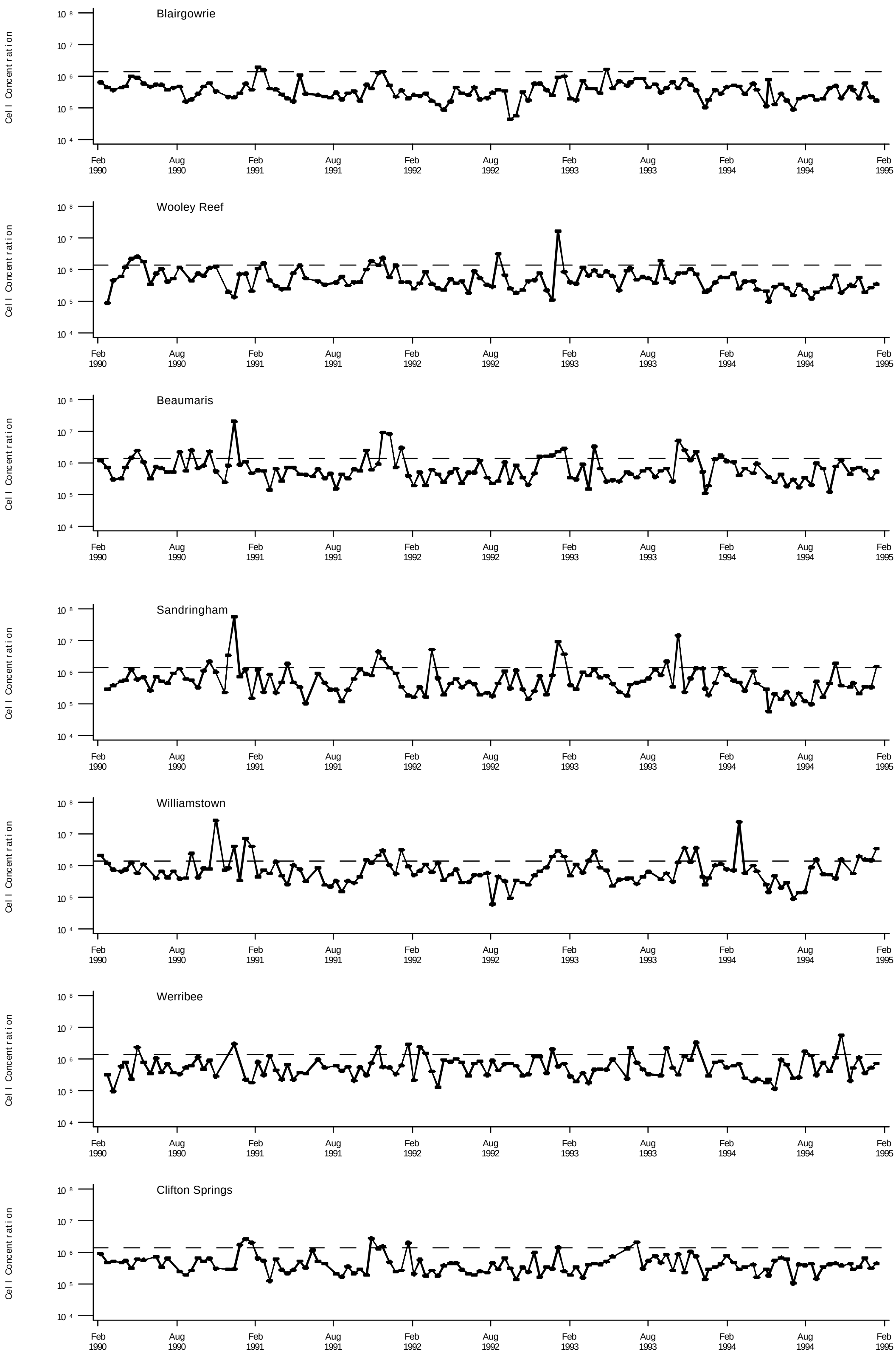

Figure 4: Time distribution of total cell concentration (number of cells L^{-1} expressed in exponential form) of all phytoplankton species for each site. The dashed line indicates the 90 percentage quantile (1.40 x 10^6 cells L-1) over all site and time combinations. The x-axis labels indicate the end of the specified month.

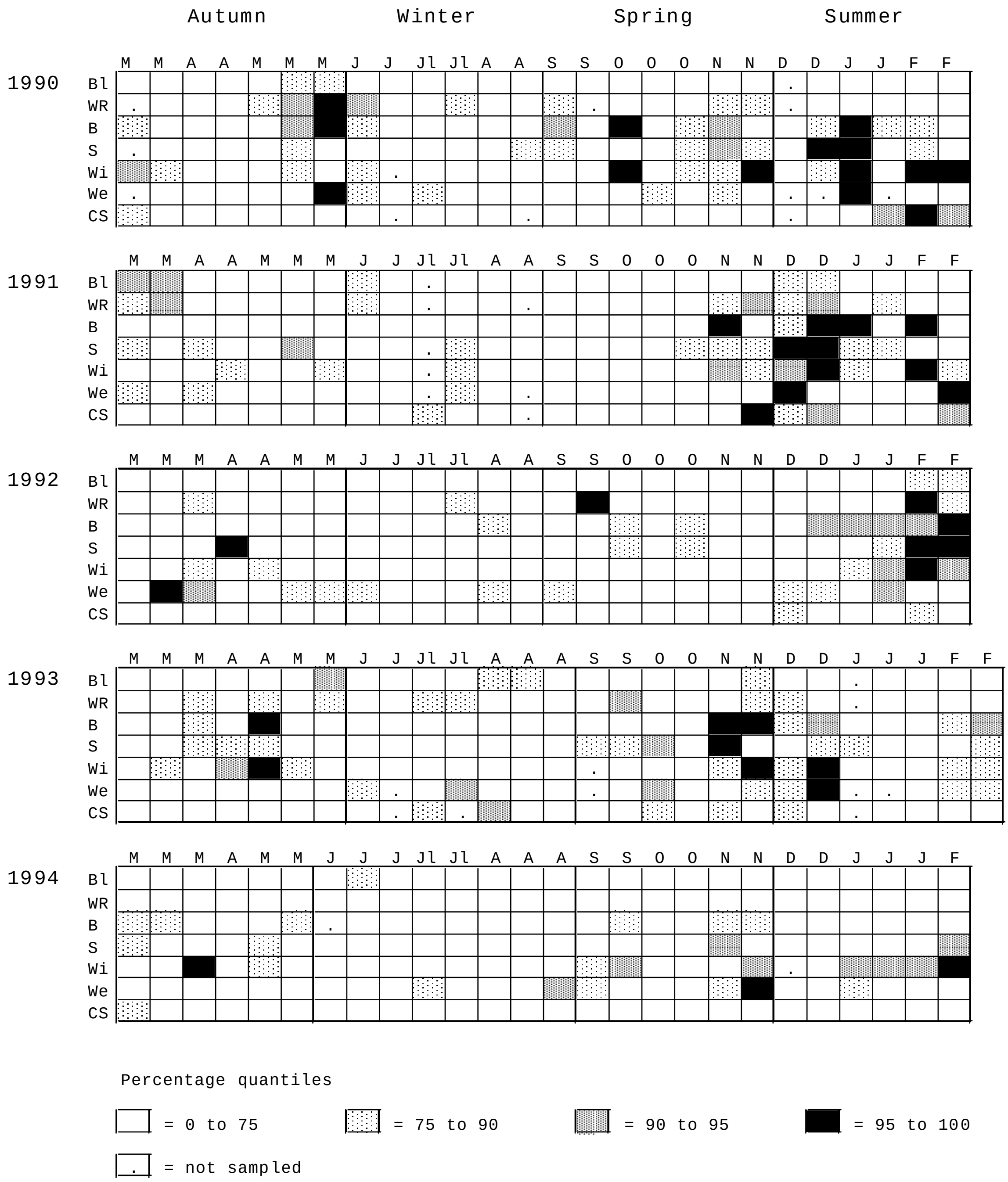

Figure 5: Summary of percentage quantiles for total cell concentration (cells L^{-1}) of all phytoplankton species for individual sites and cruises.

Seasonal mean cell concentrations for total phytoplankton were highest in summer, spring and autumn with 1.50×10^6, 8.31×10^5, and 7.30×10^5 cells L^{-1} respectively. Mean cell concentrations were lowest in winter at 4.76×10^5 cells L^{-1}. Summer had by far the highest number of samples (44) with values greater than the 90% quantile. There were 22 such samples in spring, 18 in autumn and only four samples in winter with values above the 90% quantile (1.40×10^6 cells L^{-1}) (Figure 5, Table 7).

High mean cell concentrations of 1.31×10^6, 1.30×10^6 and 1.05×10^6 cells L^{-1} were observed for Williamstown, Sandringham and Beaumaris respectively. Werribee and Wooley Reef had lower cell concentrations at 7.40×10^5 and 7.34×10^5 cells L^{-1} respectively. Mean cell concentrations were lowest at Clifton Springs (5.23×10^5) and Blairgowrie (4.20×10^5). The number of samples with cell concentrations greater than the 90% quantile (1.40×10^6 cells L^{-1}) varied markedly among sites; in decreasing order these were 24 for Williamstown, 20 for Beaumaris, 13 for Sandringham, 12 for Werribee, nine for Wooley Reef, seven for Clifton Springs and three for Blairgowrie.

Higher cell concentrations tended to occur in summer and spring, but not consistently at all sites. Autumn was the only season in which total cell concentration values were greater than the 90% quantile at Blairgowrie (Table 8). Wooley Reef also had more cell concentration values greater than 1.4030×10^6 during autumn (3) than summer (2). Highest mean seasonal cell concentrations during summer were recorded for Sandringham (3.04×10^6 cells L^{-1}), Beaumaris (2.16×10^6), Williamstown (1.77×10^6) and Werribee (1.00×10^6) (Table 8). There were also more samples with values above the 90% quantile during summer for three of these sites - Sandringham (7), Beaumaris (11), and Williamstown (14) - than were recorded during the other three seasons collectively (Figure 5, Table 8). There were five samples with values above the 90% quantile in summer for both Werribee and Clifton Springs, but only two for Wooley Reef and none for Blairgowrie. During spring there were six samples with values greater than the 90% quantile from both Williamstown and Beaumaris, compared with four from Sandringham, three from Wooley Reef, two from Werribee, one from Clifton Springs and none from Blairgowrie (Figure 5, Table 8). The mean cell concentration during spring was highest at Williamstown, Sandringham and Beaumaris with 1.51×10^6, 1.12×10^6 and 9.41×10^5 cells L^{-1} respectively (Table 8).

Table 8: Seasonal arithmetic mean, standard error and number of samples with total cell concentration (cells L^{-1}) greater than the 90 % quantile for all phytoplankton species combined. The 90% quantile (1.4030×10^6 cells L^{-1}) was calculated from all time and site combinations.

Site	Site code	Season	n	Mean cell concentration (cells L^{-1})	se	Samples above 90% quantile
Blairgowrie	1	Autumn	34	4.92×10^5	7.36×10^4	3
		Winter	32	4.06×10^5	4.28×10^4	0
		Spring	33	3.36×10^5	2.97×10^4	0
		Summer	29	4.48×10^5	5.94×10^4	0
		Total	128	4.20×10^5	2.73×10^4	3
Wooley Reef	4	Autumn	33	6.63×10^5	9.55×10^4	3
		Winter	31	5.28×10^5	6.69×10^4	1
		Spring	32	6.77×10^5	1.11×10^5	3
		Summer	29	1.10×10^6	5.43×10^5	2
		Total	125	7.34×10^5	1.32×10^5	9
Beaumaris	5	Autumn	34	7.00×10^5	1.09×10^5	3
		Winter	32	4.64×10^5	4.00×10^4	0
		Spring	33	9.41×10^5	1.79×10^5	6
		Summer	31	2.16×10^6	7.09×10^5	11
		Total	130	1.05×10^6	1.84×10^5	20
Sandringham	6	Autumn	33	7.39×10^5	1.52×10^5	2
		Winter	32	3.75×10^5	3.98×10^4	0
		Spring	33	1.12×10^6	4.22×10^5	4
		Summer	31	3.04×10^6	1.78×10^6	7
		Total	129	1.30×10^6	4.47×10^5	13
Williamstown	9	Autumn	34	1.52×10^6	6.75×10^5	4
		Winter	31	4.12×10^5	4.20×10^4	0
		Spring	32	1.51×10^6	8.01×10^5	6
		Summer	30	1.77×10^6	2.81×10^5	14
		Total	127	1.31×10^6	2.80×10^5	24
Werribee	11	Autumn	33	5.85×10^5	9.63×10^4	3
		Winter	30	6.29×10^5	8.47×10^4	2
		Spring	32	7.92×10^5	1.69×10^5	2
		Summer	26	1.00×10^6	1.78×10^5	5
		Total	121	7.40×10^5	6.84×10^4	12
Clifton Springs	13	Autumn	34	3.99×10^5	3.16×10^4	0
		Winter	28	5.32×10^5	7.73×10^4	1
		Spring	33	4.50×10^5	7.82×10^4	1
		Summer	29	7.42×10^5	1.23×10^5	5
		Total	124	5.23×10^5	4.17×10^4	7

Cell Concentrations of Diatomophyceae

The distribution of diatom concentrations over time was more spiky than that for total phytoplankton (Figure 6). Diatoms were not observed, during sample analysis, in 43 of the 884 phytoplankton samples collected. Nineteen of these zero concentration samples came from Clifton Springs. Another prominent feature was the relatively low concentration of diatoms at most sites in 1994.

The highest annual mean cell concentration of diatoms was observed in 1990 with $1.13x10^6$ cells L^{-1} (Table 9). Considerably lower arithmetic mean cell concentrations were observed in other years: $4.95x10^5$ in 1991, $4.51x10^5$ in 1992, $3.26x10^5$ in 1994 and $3.22x10^5$ cells L^{-1} in 1993. The 90% quantile concentration of $9.08x10^5$ cells L^{-1} was exceeded in 27 samples during both 1990 and 1991 (Figure 7, Table 9). Fewer samples with values higher than the 90% quantile were observed in subsequent years: 14 samples in 1992, 12 samples in 1993 and only eight samples in 1994. Diatoms thus appeared to decrease in concentration throughout the five years of sampling.

Higher mean cell concentrations were observed during summer ($1.10x10^6$ cells L^{-1}) than those recorded in spring, autumn and winter ($4.79x10^5$, $4.07x10^5$ and $2.07x10^5$ cells L^{-1} respectively). Likewise, there were 45 samples with values that exceeded the 90 % quantile during summer, compared with 20 samples during both spring and autumn, and only three samples in winter (Figure 7, Table 9).

The mean cell concentration of diatoms was highest at Sandringham, Williamstown and Beaumaris with $9.68x10^5$, $9.01x10^5$ and $6.56x10^5$ cells L^{-1} respectively (Table 9). Lower mean cell concentrations were observed at Wooley Reef ($4.59x10^5$ cells L^{-1}), Werribee ($3.43x10^5$), Clifton Springs ($2.03x10^5$) and Blairgowrie ($2.09x10^5$). A similar pattern was observed when considering the number of samples with values greater than the 90% quantile. Thus, there were 23 samples for Williamstown, 16 for Sandringham, 15 for Beaumaris, 13 for Wooley Reef, 10 for Werribee, seven for Clifton Springs and four for Blairgowrie (Figure 7, Table 9).

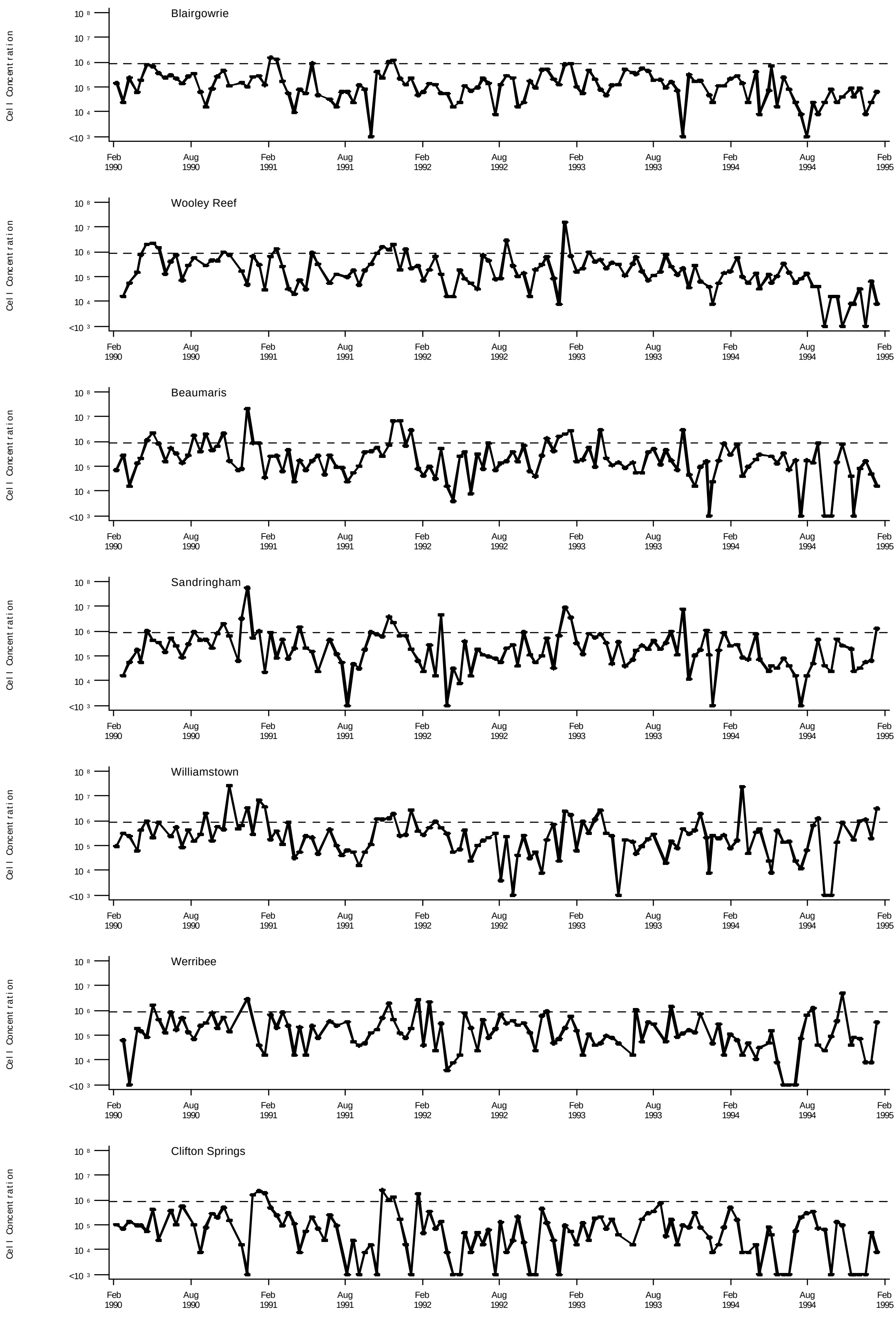

Figure 6: Time distribution of total cell concentration (number of cells L^{-1} expressed in exponential form) of diatoms for each site. The dashed line indicates the 90 percentage quantile (9.0780×10^5 cells L^{-1}) over all site and time combinations. The x axis labels indicate the end of the specified month. A concentration of $<10^3$ cells L^{-1} was plotted for those samples in which no diatoms were observed.

Table 9: Summary of total cell concentrations (cells L^{-1}) of diatoms: values corresponding to percentile ranges, number of samples in percentage quantiles and descriptive statistics.

Percentile range	Range of values	Number of samples
0 to 75	0 to 3.77×10^5	663
>75 to 90	3.77×10^5 to 9.08×10^5	133
>90 to 95	9.08×10^5 to 1.86×10^6	44
>95 to 100	1.86×10^6 to 5.54×10^7	44
Total		**884**

	n	Arithmetic Mean	se	90 to 95 %	95 to 100 %	Total (> 90 %)
1990	169	1.13×10^6	3.79×10^5	10	17	27
1991	174	4.95×10^5	6.89×10^4	17	10	27
1992	182	4.51×10^5	1.05×10^5	5	9	14
1993	179	3.21×10^5	5.20×10^4	7	5	12
1994	180	3.26×10^5	1.33×10^5	5	3	8
Autumn	235	4.07×10^5	1.04×10^5	12	8	20
Winter	216	2.07×10^5	1.53×10^4	3	0	3
Spring	228	4.79×10^5	1.22×10^5	10	10	20
Summer	205	1.10×10^6	3.04×10^5	19	26	45
Blairgowrie	128	2.09×10^5	2.38×10^4	4	0	4
Wooley Reef	125	4.59×10^5	1.28×10^5	8	5	13
Beaumaris	130	6.56×10^5	1.74×10^5	4	11	15
Sandringham	129	9.68×10^5	4.38×10^5	7	9	16
Williamstown	127	9.01×10^5	2.78×10^5	12	11	23
Werribee	121	3.43×10^5	5.84×10^4	5	5	10
Clifton Springs	124	2.03×10^5	3.80×10^4	4	3	7
Total				**44**	**44**	**88**

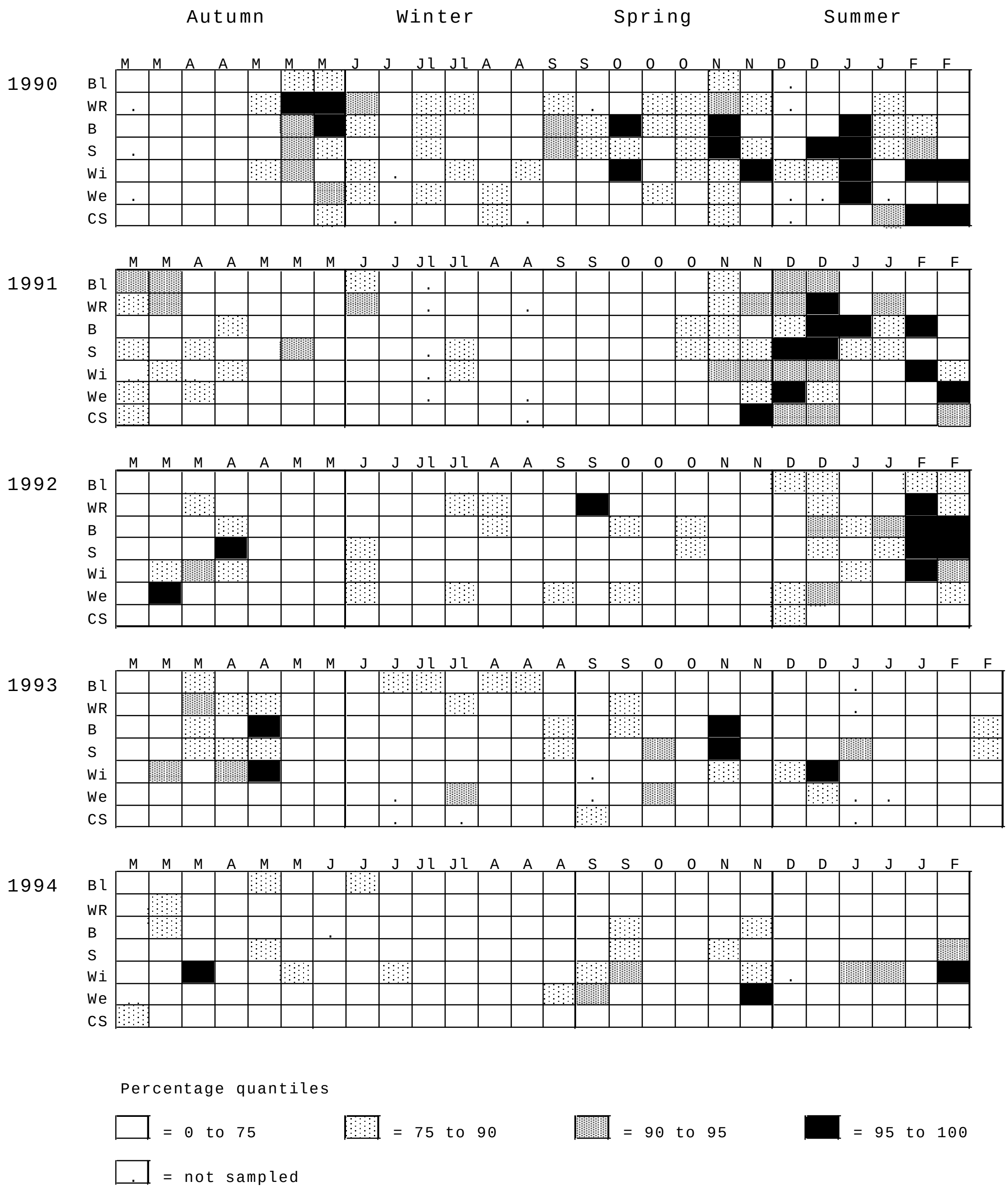

Figure 7: Summary of percentage quantiles for total cell concentration (cells L^{-1}) of diatoms for individual sites and cruises.

Cell Concentrations of Dinophyceae

Relatively high cell concentrations of dinoflagellates were found during the first two years of sampling at most sites (Figure 8). Also evident from the time distribution was the number of samples (88) for which zero concentrations were recorded. Representatives of this class were likely to have been present in these samples, but they were not observed during cell enumeration.

Highest annual mean cell concentrations of dinoflagellates were observed in 1991 and 1990 with 8.93×10^4 and 7.78×10^4 cells L^{-1} respectively. Lower concentrations of dinoflagellates were found in 1992 (5.67×10^4 cells L^{-1}), 1993 (4.91×10^4) and 1994 (4.47×10^4). The 90% quantile value for total cell concentration of dinoflagellates was 1.40×10^5 cells L^{-1}. There were 30 and 22 samples with values greater than the 90% quantile in 1991 and 1990, but only 18, 12 and five samples in 1992, 1993 and 1994 respectively (Figure 9, Table 10). These results show that dinoflagellate blooms were more frequent during the first two years of sampling.

Summer had the highest mean seasonal cell concentration with 8.81×10^4 cells L^{-1}. Lower concentrations were observed in autumn (6.59×10^4 cells L^{-1}), spring (5.05×10^4) and winter (4.99×10^4). Summer and autumn had 27 and 24 samples with values greater than 1.40×10^5 cells L^{-1}, compared with 17 and 19 samples in spring and winter respectively.

Spatially, highest mean cell concentrations were observed at Williamstown (8.86×10^4 cells L^{-1}), Beaumaris (8.33×10^4) and Werribee (7.37×10^4). Slightly lower values were recorded at Sandringham (6.05×10^4 cells L^{-1}), Clifton Springs (5.72×10^4) and Wooley Reef (5.59×10^4). The mean cell concentration at Blairgowrie was by far the lowest at only 2.31×10^4 cells L^{-1}. The number of samples with values greater than the 90% quantile (1.40×10^5 cells L^{-1}) also varied between sites. There were 25 samples greater than the 90% quantile for Williamstown, 18 for Beaumaris, 16 for Werribee, 11 for Sandringham, 10 for Wooley Reef, six for Clifton Springs and only one sample for Blairgowrie.

An interaction between year and season was apparent. For example, during autumn there were nine samples with values greater than the 90% quantile in 1992, seven in both 1990 and 1991, but only one sample in 1994 and no samples in 1993. Similarly, there were differences between years during summer, although it was 1991 that had the highest number (12) of samples with values greater than the 90% quantile. There were only six samples with values greater than the 90% quantile in 1993, and three in 1990, 1992 and 1994.

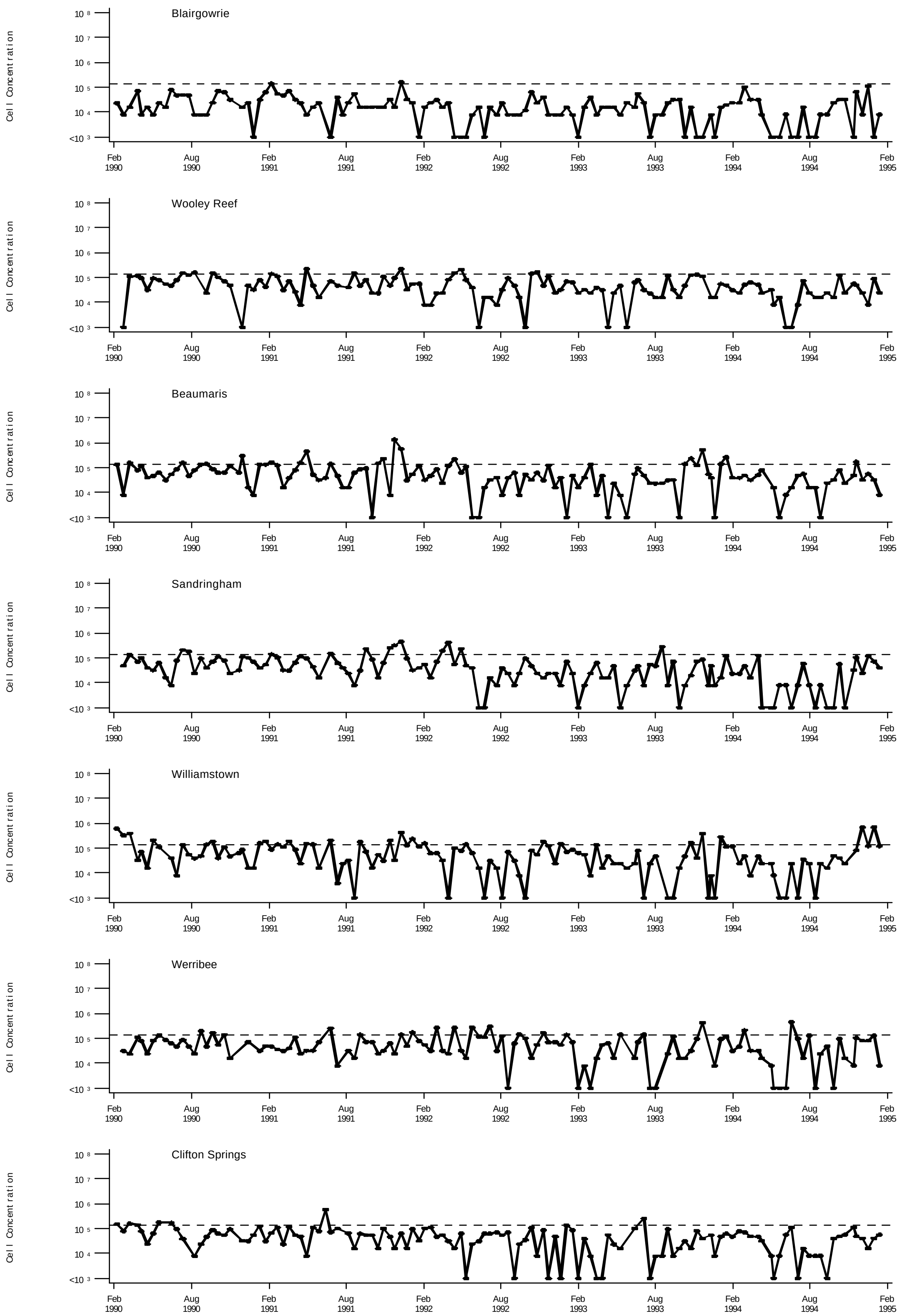

Figure 8: Time distribution of total cell concentration (number of cells L^{-1} expressed in exponential form) of dinoflagellates for each site. The dashed line indicates the 90 percentage quantile (1.40×10^5 cells L^{-1}) over all site and time combinations. The x axis labels indicate the end of the specified month. A concentration of $<10^3$ cells L^{-1} was plotted for those samples in which no dinoflagellates were observed.

Table 10: Summary of total cell concentrations (cells L^{-1}) of dinoflagellates: values corresponding to percentile ranges, number of samples in percentage quantiles and descriptive statistics. Note: three samples had cell concentrations corresponding to the 90% quantile.

Percentile range	Range of values	Number of samples
0 to 75	0 to 7.8500×10^4	663
>75 to 90	7.8500×10^4 to 1.4000×10^5	134
>90 to 95	1.4000×10^5 to 1.8700×10^5	43
>95 to 100	1.8700×10^5 to 1.3400×10^6	44
Total		**884**

	n	Arithmetic Mean	se	90 to 95 %	95 to 100 %	Total (> 90 %)
1990	169	7.7815×10^4	5.6180×10^3	15	7	22
1991	174	8.9273×10^4	1.0131×10^4	14	16	30
1992	182	5.6679×10^4	4.7230×10^3	9	9	18
1993	179	4.9144×10^4	5.5190×10^3	4	8	12
1994	180	4.4695×10^4	6.2220×10^3	1	4	5
Autumn	235	6.5897×10^4	5.0230×10^3	10	14	24
Winter	216	4.9889×10^4	4.7880×10^3	11	8	19
Spring	228	5.0525×10^4	3.3680×10^3	12	5	17
Summer	205	8.8099×10^4	9.7240×10^3	10	17	27
Blairgowrie	128	2.3077×10^4	2.3340×10^3	1	0	1
Wooley Reef	125	5.5896×10^4	4.3270×10^3	7	3	10
Beaumaris	130	8.3308×10^4	1.2480×10^4	9	9	18
Sandringham	129	6.0467×10^4	6.6650×10^3	2	9	11
Williamstown	127	8.8582×10^4	1.0726×10^4	13	12	25
Werribee	121	7.3749×10^4	7.2190×10^3	7	9	16
Clifton Springs	124	5.7234×10^4	5.7790×10^3	4	2	6
Total				**43**	**44**	**87**

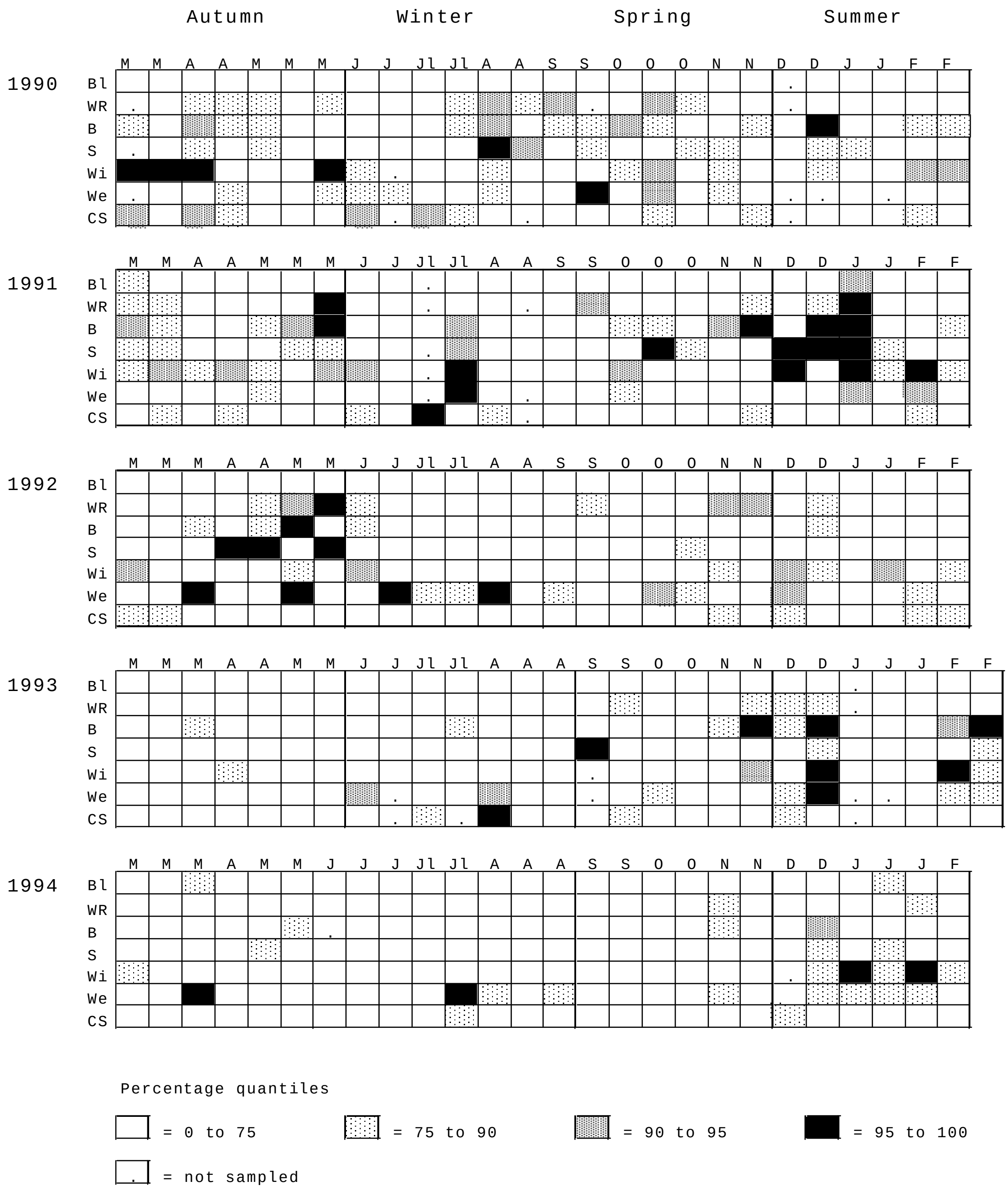

Figure 9: Summary of percentage quantiles for total cell concentration (cells L^{-1}) of dinoflagellates for individual sites and cruises.

3.3. Species Diversity

Mean values of the Shannon-Weaver diversity index (H’) were calculated for groups of phytoplankton samples falling within specified quantile ranges for the total cell concentration of all species combined (Table 11). Diversity was highest for the 50-75% quantile range at 3.03, but decreased to 2.70 for the 75-90% range and was lowest at 1.91 for the 90-100% grouping representative of algal blooms. Species evenness (J’) decreased from 0.84 for the 0-50% range to 0.47 for the 90-100% range, and hence showed a more marked variation than for H’. This suggests that the individuals in the upper quantile range samples were unevenly spread among the species present. Species richness displayed an opposite trend to that for evenness, increasing as cell concentration increased. The mean number of species per sample in the 0-50% quantile range (11.26) was considerably lower than that for the other three quantile groups (15.38 - 16.89).

The results for the chlorophyll ***a*** percentile ranges, based on the structure of their matching phytoplankton samples, revealed similar trends in diversity (H’) and evenness (J’) (Table 11). However, the differences between groups were relatively small. Species richness was also similar, as the number of species was again clearly lowest in the 0-50% quantile range.

Considered together these results show that the plankton of the high cell concentration samples (90-100% range), indicative of algal blooms, was mainly comprised of one or a few highly abundant species. However, species richness was apparently not reduced during times of algal blooms in Port Phillip Bay, although concentrations of the non-bloom species must have been relatively low.

Table 11: Mean values of Shannon-Weaver Index (H’), species evenness (J’) and species richness (SR) for groups of phytoplankton samples corresponding with specified quantile ranges of chlorophyll a and total cell concentration of all species combined. Note only 854 of the 876 chlorophyll *a* samples had matching phytoplankton samples.

Quantile ranges	n	H’	J’	SR
Chlorophyll ***a***				
0-50%	427	2.7907	0.7932	12.20
50-75%	213	2.8667	0.7670	14.21
75-90%	128	2.7875	0.7249	15.27
90-100%	86	2.6800	0.6738	16.62
	854			
Total cell concentration				
0-50%	442	2.8894	0.8439	11.26
50-75%	221	3.0305	0.7755	15.38
75-90%	133	2.6989	0.6702	16.50
90-100%	88	1.9125	0.4691	16.89
	884			

3.4. Dominant Species

Two approaches were used to determine the dominant species occurring during algal blooms. The first approach involved an examination of the cell concentrations and relative abundances of numerically dominant phytoplankton species from samples with a total cell concentration greater than the 90% quantile value of 1.4030×10^6 cells L^{-1}. This was derived from all five year time and site combinations. Results are given for each year in Tables 12-16.

The number of species with a relative abundance of 10% or higher at a given site during a given cruise varied from one to five. For example, one sample from Williamstown (cruise 1) in autumn 1990 had five species with relative abundances varying from 10% to 19% (Table 12). However, many samples had only one dominant species; e.g. in summer 1990 *Skeletonema costatum* comprised 98% and 99% of the total cell concentration of two samples from Beaumaris and Sandringham, respectively (cruise 23, Table 12).

There were 28 abundant species or taxa with relative abundances greater than 10% in the 88 samples with a total cell concentration greater than the 90% quantile value. The class with the most representatives was the Diatomophyceae with 12 species: *Cerataulina pelagica*, *Chaetoceros* spp., *Detonula confervacea, Leptocylindrus minimus*, *Minidiscus trioculatus*, *Nitzschia* spp., *Pseudonitzschia pseudodelicatissima, Pseudonitzschia pungens, Rhizosolenia cf. chunii, Rhizosolenia setigera*, *Skeletonema costatum* and *Thalassiosira* spp. (Tables 12-16). Other phytoplankton classes (and species) included: Dinophyceae (*Alexandrium catenella*, *Gymnodinium* spp, *Prorocentrum micans* and *Scrippsiella* spp.); Raphidophyceae (*Heterosigma carterae*); Cryptophyceae (*Hemiselmis virescens, Plagioselmis prolonga* and *Teleaulax acuta*); Euglenophyceae (*Euglena* spp. and *Eutreptiella* spp.); Prymnesiophyceae (*Chrysochromulina* spp. and *Gephyrocapsa oceanica*); Prasinophyceae (*Nephroselmis pyriformis, Nephroselmis rotunda* and *Pyramimonas* spp.); and Chlorophyceae (*Oltmannisiellopsis unicellularis*).

The most frequent 'bloom' species was the diatom *Skeletonema costatum*, which occurred in 50 of the 88 samples with total cell concentrations greater than the 90% quantile value. A maximum concentration of 5.50×10^7 cells L^{-1} was recorded at Sandringham in the summer of 1990 (cruise 23, Table 12). This species was numerically dominant at some time at all of the seven sites, although it was most frequently abundant at Williamstown (15 of the 88 samples), Beaumaris (13 samples) and Sandringham (11 samples). *S. costatum* was dominant in all seasons, except winter, but was particularly abundant in summer (33 samples). It was less abundant in the summers of 1993 and 1994, but was highly abundant in the summer of 1990 when it was the numerically dominant species in all ten samples with a relative abundance varying from 60% to 99% (Table 12). *S. costatum* was also numerically dominant at some time each autumn, and in the spring of 1990 and 1993.

The second most frequently occurring 'bloom' species or taxa was another diatom, *Chaetoceros* spp. This species occurred in 19 of the 88 samples with cell concentrations greater than the 90% quantile value (Tables 12-16), and was very dominant in a few samples. For example, a maximum concentration of 2.70×10^6 cells L^{-1} was observed at Wooley Reef in the spring of 1992 with a relative abundance of

86% (cruise 67, Table 14). However, this species occurred more often with relative abundances of 10% to 35%. *Chaetoceros* spp. was dominant at all sites (except Blairgowrie) on some occasions, but was most frequently dominant at Williamstown (six samples) and Beaumaris (five samples). It was usually abundant from spring to autumn, but was dominant at Werribee in the winter of 1993

A bloom of the potentially toxic diatom *Pseudonitzschia pseudodelicatissima* was observed in late spring and summer of 1991. This was the first record of this species occurring in Port Phillip Bay. A maximum concentration of 2.50x10^6 cells L^{-1} was found at Sandringham in early summer (cruise 47, Table 13). This species was recorded as numerically dominant on four consecutive cruises (45-48), and comprised 12% to 89% of the total cell concentration for individual samples. It was dominant at some time at Wooley Reef, Sandringham, Williamstown, Werribee and Clifton Springs. For example, during early summer (cruise 48) *P. pseudodelicatissima* had a relative abundance of 74% at Wooley Reef, 72% at Sandringham, 51% at Williamstown and 86% at Clifton Springs (Table 13). The only other occasion when this species was dominant was at Beaumaris during the summer of 1992, contributing 27% of the total cell concentration (cruise 74, Table 14). Fortunately, the Bay strains of *P. pseudodelicatissima* have never produced detectable concentrations of domoic acid, the toxin responsible for causing amnesic shellfish poisoning overseas.

The only numerically dominant species in the present dataset known to be toxic was the dinoflagellate *Alexandrium catenella*. This species had a relative abundance of 29% in early summer of 1994 at Williamstown (cruise 128, Table 16).

A further species of interest was the diatom *Rhizosolenia cf. chunii*. Blooms of this nuisance species were responsible for causing an intense bitter taste in bivalve shellfish in late winter and early spring of 1987, 1993 and 1994. *Rhizosolenia* cf. *chunii* had a relative abundance of 37% at Werribee in winter 1994 and 79% at Williamstown in spring 1994 (Table 16).

The second approach to assessing the key species involved in algal blooms, i.e. determining the mean cell concentrations and relative abundances of dominant phytoplankton species within each year and season (calculated from samples with total cell concentration greater than the 90% quantile value), reduced the number of dominants to 11 species or taxa (Table 17). There were seven Diatomophyceae (*Chaetoceros* spp., *Leptocylindrus minimus*, *Minidiscus trioculatus*, *Nitzschia* spp., *Pseudonitzschia pseudodelicatissima*, *Rhizosolenia* cf. *chunii* and *Skeletonema costatum*), two Cryptophyceae (*Plagioselmis prolonga* and *Teleaulax acuta*), and single representatives from the Euglenophyceae (*Eutreptiella* spp.) and Prasinophyceae (*Pyramimonas* spp.) (Table 17).

There was considerable interannual variation in the composition of the dominant species. Nine of the eleven species were numerically dominant in only one or two years during the five-year study. However, *Skeletonema costatum* and *Chaetoceros* spp. were dominant species in five and four years, respectively. *Skeletonema costatum* dominated from early spring and/or summer to autumn (Table 17). This species had relative abundances of 78% and 94% in spring and summer 1990 and 44% in autumn 1991. In other years *S. costatum* had relative abundances of 47% and 69% in summer 1991 and autumn 1992; 71% and 52% in summer 1992 and autumn 1993; 18% in spring 1993 and 97% in autumn 1994; and 59% in summer 1994. *Chaetoceros* spp., on the other hand, was usually dominant in autumn, winter or spring. This latter species had relative abundances of 12% in autumn 1990; 10% and 12% in autumn and spring 1991; 86% in spring 1992; and 16%, 17% and 12% in autumn, winter and spring 1993. *Chaetoceros* spp. was not a numerically dominant species in 1994.

Table 12: Cell concentration and relative abundance (%) of dominant phytoplankton species for 1990 samples with a total cell concentration greater than the 90% quantile value (1.4030×10^6 cells L^{-1}). The species listed comprised at least 10% of the total cell concentration for the relevant sample.

Season	Cruise	Site	Species	Spec Code	Conc. (cells L^{-1})	Abund %
Autumn	1	Williamstown	*Plagioselmis prolonga*	04009	3.80×10^5	(19)
Autumn	1	Williamstown	*Gephyrocapsa oceanica*	06010	3.20×10^5	(16)
Autumn	1	Williamstown	*Chrysochromulina unidentified spp.*	06034	3.20×10^5	(16)
Autumn	1	Williamstown	*Scrippsiella unidentified spp.*	01176	2.30×10^5	(11)
Autumn	1	Williamstown	*Gymnodinium unidentified spp.*	01115	2.10×10^5	(10)
Autumn	6	Wooley Reef	*Leptocylindrus minimus*	02047	1.70×10^6	(78)
Autumn	6	Beaumaris	*Leptocylindrus minimus*	02047	7.60×10^5	(53)
Autumn	6	Beaumaris	*Skeletonema costatum*	02076	1.60×10^5	(11)
Autumn	7	Wooley Reef	*Leptocylindrus minimus*	02047	1.90×10^6	(75)
Autumn	7	Beaumaris	*Leptocylindrus minimus*	02047	1.90×10^6	(78)
Autumn	7	Werribee	*Chaetoceros unidentified spp.*	02174	1.30×10^6	(56)
Autumn	7	Werribee	*Pyramimonas unidentified spp.*	07026	3.80×10^5	(16)
Winter	8	Wooley Reef	*Leptocylindrus minimus*	02047	1.30×10^6	(74)
Spring	14	Beaumaris	*Pseudonitzschia pungens*	02165	1.60×10^6	(74)
Spring	16	Beaumaris	*Skeletonema costatum*	02076	7.60×10^5	(30)
Spring	16	Beaumaris	*Cerataulina pelagica*	02016	5.30×10^5	(21)
Spring	16	Beaumaris	*Pseudonitzschia pungens*	02165	4.50×10^5	(18)
Spring	16	Williamstown	*Chaetoceros unidentified spp.*	02174	8.20×10^5	(35)
Spring	16	Williamstown	*Skeletonema costatum*	02076	4.10×10^5	(17)
Spring	16	Williamstown	*Pseudonitzschia pungens*	02165	3.50×10^5	(15)
Spring	16	Williamstown	*Cerataulina pelagica*	02016	2.40×10^5	(10)
Spring	19	Beaumaris	*Skeletonema costatum*	02076	1.50×10^6	(66)
Spring	19	Sandringham	*Skeletonema costatum*	02076	1.40×10^6	(66)
Spring	20	Williamstown	*Skeletonema costatum*	02076	2.50×10^7	(96)
Summer	22	Sandringham	*Skeletonema costatum*	02076	3.10×10^6	(92)
Summer	23	Beaumaris	*Skeletonema costatum*	02076	2.00×10^7	(98)
Summer	23	Sandringham	*Skeletonema costatum*	02076	5.50×10^7	(99)
Summer	23	Williamstown	*Skeletonema costatum*	02076	3.20×10^6	(79)
Summer	23	Williamstown	*Plagioselmis prolonga*	04009	5.30×10^5	(13)
Summer	23	Werribee	*Skeletonema costatum*	02076	2.80×10^6	(95)
Summer	24	Clifton Springs	*Skeletonema costatum*	02076	1.60×10^6	(94)
Summer	25	Williamstown	*Skeletonema costatum*	02076	4.30×10^6	(60)
Summer	25	Williamstown	*Chaetoceros unidentified spp.*	02174	1.40×10^6	(20)
Summer	25	Clifton Springs	*Skeletonema costatum*	02076	2.20×10^6	(85)
Summer	26	Williamstown	*Skeletonema costatum*	02076	3.00×10^6	(74)
Summer	26	Clifton Springs	*Skeletonema costatum*	02076	1.90×10^6	(96)

Table 13: Cell concentration and relative abundance (%) of dominant phytoplankton species for 1991 samples with a total cell concentration above the 90% quantile value ($1.4030x10^6$ cells L^{-1}). The species listed comprised at least 10% of the total cell concentration for the relevant sample.

Season	Cruise	Site	Species	Spec Code	Conc. (cells L^{-1})	Abund %
Autumn	27	Blairgowrie	*Skeletonema costatum*	02076	$1.20x10^6$	(64)
Autumn	28	Blairgowrie	*Skeletonema costatum*	02076	$1.10x10^6$	(72)
Autumn	28	Wooley Reef	*Nitzschia unidentified spp.*	02188	$7.80x10^5$	(50)
Autumn	28	Wooley Reef	*Chaetoceros unidentified spp.*	02174	$1.90x10^5$	(12)
Autumn	32	Sandringham	*Skeletonema costatum*	02076	$5.60x10^5$	(31)
Autumn	32	Sandringham	*Chaetoceros unidentified spp.*	02174	$3.10x10^5$	(17)
Winter			(no samples above 90% quantile)			
Spring	45	Beaumaris	*Eutreptiella unidentified spp.*	05007	$1.60x10^6$	(65)
Spring	45	Williamstown	*Chaetoceros unidentified spp.*	02174	$8.60x10^5$	(58)
Spring	45	Williamstown	*Pseudonitzschia pseudodelicatissima*	02164	$1.80x10^5$	(12)
Spring	46	Wooley Reef	*Pseudonitzschia pseudodelicatissima*	02164	$1.50x10^6$	(82)
Spring	46	Clifton Springs	*Pseudonitzschia pseudodelicatissima*	02164	$2.40x10^6$	(89)
Summer	47	Sandringham	*Pseudonitzschia pseudodelicatissima*	02164	$2.50x10^6$	(57)
Summer	47	Sandringham	*Skeletonema costatum*	02076	$9.90x10^5$	(22)
Summer	47	Williamstown	*Skeletonema costatum*	02076	$5.50x10^5$	(27)
Summer	47	Williamstown	*Pseudonitzschia pseudodelicatissima*	02164	$3.70x10^5$	(18)
Summer	47	Williamstown	*Chaetoceros unidentified spp.*	02174	$2.20x10^5$	(11)
Summer	47	Werribee	*Pseudonitzschia pseudodelicatissima*	02164	$1.60x10^6$	(68)
Summer	48	Wooley Reef	*Pseudonitzschia pseudodelicatissima*	02164	$1.70x10^6$	(74)
Summer	48	Wooley Reef	*Skeletonema costatum*	02076	$2.80x10^5$	(12)
Summer	48	Beaumaris	*Skeletonema costatum*	02076	$5.60x10^6$	(61)
Summer	48	Sandringham	*Pseudonitzschia pseudodelicatissima*	02164	$1.90x10^6$	(72)
Summer	48	Sandringham	*Skeletonema costatum*	02076	$2.80x10^5$	(11)
Summer	48	Williamstown	*Pseudonitzschia pseudodelicatissima*	02164	$1.50x10^6$	(51)
Summer	48	Williamstown	*Plagioselmis prolonga*	04009	$7.20x10^5$	(25)
Summer	48	Clifton Springs	*Pseudonitzschia pseudodelicatissima*	02164	$1.30x10^6$	(86)
Summer	49	Beaumaris	*Skeletonema costatum*	02076	$5.70x10^6$	(70)
Summer	51	Beaumaris	*Skeletonema costatum*	02076	$2.70x10^6$	(91)
Summer	51	Williamstown	*Skeletonema costatum*	02076	$1.50x10^6$	(49)
Summer	51	Williamstown	*Detonula confervacea*	02178	$5.60x10^5$	(18)
Summer	52	Werribee	*Skeletonema costatum*	02076	$2.40x10^6$	(83)
Summer	52	Clifton Springs	*Skeletonema costatum*	02076	$1.50x10^6$	(76)
Summer	52	Clifton Springs	*Chaetoceros unidentified spp.*	02174	$2.20x10^5$	(11)

Table 14: Cell concentration and relative abundance (%) of dominant phytoplankton species for 1992 samples with a total cell concentration above the 90% quantile value ($1.4030x10^6$ cells L^{-1}). The species listed comprised at least 10% of the total cell concentration for the relevant sample.

Season	Cruise	Site	Species	Spec Code	Conc. (cells L^{-1})	Abund %
Autumn	54	Werribee	*Skeletonema costatum*	02076	$2.10x10^6$	(89)
Autumn	55	Werribee	*Plagioselmis prolonga*	04009	$6.00x10^5$	(40)
Autumn	55	Werribee	*Euglena unidentified spp.*	05006	$3.90x10^5$	(26)
Autumn	55	Werribee	*Gymnodinium unidentified spp.*	01115	$1.60x10^5$	(11)
Autumn	56	Sandringham	*Skeletonema costatum*	02076	$4.10x10^6$	(80)
Winter			(no samples above 90% quantile)			
Spring	67	Wooley Reef	*Chaetoceros unidentified spp.*	02174	$2.70x10^6$	(86)
Summer	74	Beaumaris	*Skeletonema costatum*	02076	$4.80x10^5$	(31)
Summer	74	Beaumaris	*Pseudonitzschia pseudodelicatissima*	02164	$4.20x10^5$	(27)
Summer	74	Beaumaris	*Detonula confervacea*	02178	$2.70x10^5$	(17)
Summer	75	Beaumaris	*Heterosigma carterae*	03007	$1.10x10^6$	(68)
Summer	75	Beaumaris	*Chaetoceros unidentified spp.*	02174	$2.40x10^5$	(15)
Summer	76	Beaumaris	*Chaetoceros unidentified spp.*	02174	$1.40x10^6$	(82)
Summer	76	Williamstown	*Heterosigma carterae*	03007	$1.50x10^6$	(80)
Summer	76	Werribee	*Heterosigma carterae*	03007	$1.75x10^6$	(88)
Summer	77	Wooley Reef	*Skeletonema costatum*	02076	$1.40x10^7$	(87)
Summer	77	Beaumaris	*Skeletonema costatum*	02076	$1.20x10^6$	(54)
Summer	77	Beaumaris	*Chaetoceros unidentified spp.*	02174	$7.00x10^5$	(31)
Summer	77	Sandringham	*Skeletonema costatum*	02076	$8.60x10^6$	(95)
Summer	77	Williamstown	*Skeletonema costatum*	02076	$2.00x10^6$	(69)
Summer	77	Williamstown	*Chaetoceros unidentified spp.*	02174	$4.20x10^5$	(15)
Summer	78	Beaumaris	*Skeletonema costatum*	02076	$2.50x10^6$	(90)
Summer	78	Sandringham	*Skeletonema costatum*	02076	$3.20x10^6$	(88)
Summer	78	Williamstown	*Skeletonema costatum*	02076	$1.60x10^6$	(83)

Table 15: Cell concentration and relative abundance (%) of dominant phytoplankton species for 1993 samples with a total cell concentration above the 90% quantile value (1.4030×10^6 cells L^{-1}). The species listed comprised at least 10% of the total cell concentration for the relevant sample.

Season	Cruise	Site	Species	Spec Code	Conc. (cells L^{-1})	Abund %
Autumn	82	Williamstown	*Skeletonema costatum*	02076	1.00×10^6	(71)
Autumn	83	Beaumaris	*Skeletonema costatum*	02076	2.10×10^6	(64)
Autumn	83	Beaumaris	*Chaetoceros unidentified spp.*	02174	4.90×10^5	(15)
Autumn	83	Williamstown	*Skeletonema costatum*	02076	1.60×10^6	(58)
Autumn	83	Williamstown	*Chaetoceros unidentified spp.*	02174	8.40×10^5	(30)
Autumn	85	Blairgowrie	*Pyramimonas unidentified spp.*	07026	1.20×10^6	(74)
Winter	89	Werribee	*Chaetoceros unidentified spp.*	02174	7.30×10^5	(33)
Winter	89	Werribee	*Pyramimonas unidentified spp.*	07026	5.60×10^5	(25)
Winter	89	Werribee	*Plagioselmis prolonga*	04009	2.60×10^5	(12)
Winter	89	Werribee	*Chrysochromulina unidentified spp.*	06034	2.30×10^5	(10)
Winter	90	Clifton Springs	*Pyramimonas unidentified spp.*	07026	5.60×10^5	(27)
Winter	90	Clifton Springs	*Teleaulax acuta*	04013	5.10×10^5	(24)
Winter	90	Clifton Springs	*Hemiselmis virescens*	04007	2.80×10^5	(13)
Winter	90	Clifton Springs	*Plagioselmis prolonga*	04009	2.80×10^5	(13)
Spring	94	Wooley Reef	*Pseudonitzschia pungens*	02165	4.30×10^5	(23)
Spring	94	Wooley Reef	*Pyramimonas unidentified spp.*	07026	4.30×10^5	(23)
Spring	94	Wooley Reef	*Nephroselmis pyriformis*	07018	2.30×10^5	(12)
Spring	95	Sandringham	*Chaetoceros unidentified spp.*	02174	5.40×10^5	(25)
Spring	95	Werribee	*Chaetoceros unidentified spp.*	02174	8.00×10^5	(37)
Spring	95	Werribee	*Rhizosolenia setigera*	02071	2.80×10^5	(13)
Spring	97	Beaumaris	*Skeletonema costatum*	02076	1.30×10^6	(26)
Spring	97	Beaumaris	*Chaetoceros unidentified spp.*	02174	9.30×10^5	(19)
Spring	97	Beaumaris	*Thalassiosira unidentified spp.*	02203	5.10×10^5	(10)
Spring	97	Beaumaris	*Plagioselmis prolonga*	04009	5.10×10^5	(10)
Spring	97	Sandringham	*Skeletonema costatum*	02076	4.20×10^6	(29)
Spring	97	Sandringham	*Eutreptiella unidentified spp.*	05007	2.40×10^6	(17)
Spring	97	Sandringham	*Thalassiosira unidentified spp.*	02203	2.20×10^6	(15)
Spring	97	Sandringham	*Oltmannisiellopsis unicellularis*	11002	1.80×10^6	(13)
Spring	98	Beaumaris	*Nephroselmis rotunda*	07019	8.70×10^5	(35)
Spring	98	Beaumaris	*Chrysochromulina unidentified spp.*	06034	4.80×10^5	(19)
Spring	98	Beaumaris	*Eutreptiella unidentified spp.*	05007	2.80×10^5	(11)
Spring	98	Williamstown	*Plagioselmis prolonga*	04009	1.50×10^6	(42)
Spring	98	Williamstown	*Pyramimonas unidentified spp.*	07026	3.70×10^5	(10)
Summer	100	Beaumaris	*Heterosigma carterae*	03007	6.30×10^5	(28)
Summer	100	Beaumaris	*Chrysochromulina unidentified spp.*	06034	3.30×10^5	(15)
Summer	100	Beaumaris	*Plagioselmis prolonga*	04009	2.60×10^5	(12)
Summer	100	Williamstown	*Minidiscus trioculatus*	02141	1.30×10^6	(37)
Summer	100	Williamstown	*Chrysochromulina unidentified spp.*	06034	4.20×10^5	(12)
Summer	100	Werribee	*Plagioselmis prolonga*	04009	1.30×10^6	(40)
Summer	105	Beaumaris	*Skeletonema costatum*	02076	5.40×10^5	(32)
Summer	105	Beaumaris	*Plagioselmis prolonga*	04009	2.30×10^5	(14)

Table 16: Cell concentration and relative abundance (%) of dominant phytoplankton species for 1994 samples with a total cell concentration above the 90% quantile value ($1.4030x10^6$ cells L^{-1}). The species listed comprised at least 10% of the total cell concentration for the relevant sample.

Season	Cruise	Site	Species	Spec Code	Conc. (cells L^{-1})	Abund %
Autumn	108	Williamstown	*Skeletonema costatum*	02076	$2.30x10^7$	(97)
Winter	119	Werribee	*Rhizosolenia cf. chunii*	02140	$6.30x10^5$	(37)
Winter	119	Werribee	*Pyramimonas unidentified spp.*	07026	$4.60x10^5$	(27)
Winter	119	Werribee	*Teleaulax acuta*	04013	$1.84x10^5$	(11)
Spring	121	Williamstown	*Rhizosolenia cf. chunii*	02140	$1.20x10^6$	(79)
Spring	124	Sandringham	*Pyramimonas unidentified spp.*	07026	$9.60x10^5$	(51)
Spring	124	Sandringham	*Thalassiosira unidentified spp.*	02203	$3.70x10^5$	(20)
Spring	125	Williamstown	*Minidiscus trioculatus*	02141	$8.00x10^5$	(52)
Spring	125	Williamstown	*Chrysochromulina unidentified spp.*	06034	$5.80x10^5$	(38)
Spring	125	Werribee	*Minidiscus trioculatus*	02141	$4.60x10^6$	(83)
Summer	128	Williamstown	*Skeletonema costatum*	02076	$8.90x10^5$	(46)
Summer	128	Williamstown	*Alexandrium catenella*	01001	$5.60x10^5$	(29)
Summer	129	Williamstown	*Skeletonema costatum*	02076	$7.90x10^5$	(52)
Summer	129	Williamstown	*Thalassiosira unidentified spp.*	02203	$2.60x10^5$	(17)
Summer	130	Williamstown	*Prorocentrum micans*	01061	$6.20x10^5$	(43)
Summer	130	Williamstown	*Plagioselmis prolonga*	04009	$3.60x10^5$	(25)
Summer	131	Sandringham	*Skeletonema costatum*	02076	$1.10x10^6$	(75)
Summer	131	Williamstown	*Skeletonema costatum*	02076	$3.00x10^6$	(89)

Table 17: Arithmetic mean cell concentration and relative abundance (%) of dominant phytoplankton species, within each year and season, calculated from samples with total cell concentrations greater than the 90% quantile value ($1.4030x10^6$ cells L^{-1}). The species listed comprised at least 10% of the total cell concentration for the relevant year and season.

Year	Season	Species	Spec Code	Mean conc. (cells L^{-1})	Abund %
1990	Autumn	*Leptocylindrus minimus*	02047	$1.0446x10^6$	(49)
1990	Autumn	*Chaetoceros unidentified spp.*	02174	$2.6600x10^5$	(12)
1990	Winter	*Leptocylindrus minimus*	02047	$1.3000x10^6$	(74)
1990	Spring	*Skeletonema costatum*	02076	$4.8528x10^6$	(78)
1990	Summer	*Skeletonema costatum*	02076	$9.7100x10^6$	(94)
1991	Autumn	*Skeletonema costatum*	02076	$7.5250x10^5$	(44)
1991	Autumn	*Nitzschia unidentified spp.*	02188	$2.1250x10^5$	(13)
1991	Autumn	*Chaetoceros unidentified spp.*	02174	$1.7625x10^5$	(10)
1991	Winter	(no samples above 90 % quantile)			
1991	Spring	*Pseudonitzschia pseudodelicatissima*	02164	$1.0650x10^6$	(50)
1991	Spring	*Eutreptiella unidentified spp.*	05007	$4.2145x10^5$	(20)
1991	Spring	*Chaetoceros unidentified spp.*	02174	$2.5500x10^5$	(12)
1991	Summer	*Skeletonema costatum*	02076	$1.6754x10^6$	(47)
1991	Summer	*Pseudonitzschia pseudodelicatissima*	02164	$9.2977x10^5$	(26)
1992	Autumn	*Skeletonema costatum*	02076	$2.0667x10^6$	(69)
1992	Winter	(no samples above 90% quantile)			
1992	Spring	*Chaetoceros unidentified spp.*	02174	$2.7000x10^6$	(86)
1992	Summer	*Skeletonema costatum*	02076	$2.8055x10^6$	(71)
1993	Autumn	*Skeletonema costatum*	02076	$1.1808x10^6$	(52)
1993	Autumn	*Chaetoceros unidentified spp.*	02174	$3.6925x10^5$	(16)
1993	Autumn	*Pyramimonas unidentified spp.*	07026	$3.0575x10^5$	(13)
1993	Winter	*Pyramimonas unidentified spp.*	07026	$5.6000x10^5$	(26)
1993	Winter	*Chaetoceros unidentified spp.*	02174	$3.6500x10^5$	(17)
1993	Winter	*Teleaulax acuta*	04013	$2.7000x10^5$	(12)
1993	Winter	*Plagioselmis prolonga*	04009	$2.6650x10^5$	(12)
1993	Spring	*Skeletonema costatum*	02076	$8.0857x10^5$	(18)
1993	Spring	*Chaetoceros unidentified spp.*	02174	$5.1714x10^5$	(12)
1993	Spring	*Plagioselmis prolonga*	04009	$4.5057x10^5$	(10)
1993	Summer	*Plagioselmis prolonga*	04009	$4.8250x10^5$	(18)
1993	Summer	*Minidiscus trioculatus*	02141	$3.7250x10^5$	(14)
1994	Autumn	*Skeletonema costatum*	02076	$2.3000x10^7$	(97)
1994	Winter	*Rhizosolenia cf. chunii*	02140	$6.3000x10^5$	(37)
1994	Winter	*Pyramimonas unidentified spp.*	07026	$4.6000x10^5$	(27)
1994	Winter	*Teleaulax acuta*	04013	$1.8400x10^5$	(11)
1994	Spring	*Minidiscus trioculatus*	02141	$1.3520x10^6$	(52)
1994	Spring	*Rhizosolenia cf. chunii*	02140	$3.0000x10^5$	(11)
1994	Spring	*Pyramimonas unidentified spp.*	07026	$2.7550x10^5$	(11)
1994	Summer	*Skeletonema costatum*	02076	$1.1560x10^6$	(59)

4. DISCUSSION

4.1. Implications for Management of Port Phillip Bay

The temporal and spatial data on chlorophyll ***a*** in this report should be of great assistance to the Environment Protection Authority (EPA) in their current revision of the 1975 State Environment Protection Policy (SEPP) for Port Phillip Bay.

Comparisons can be made between the annual arithmetic mean concentrations of chlorophyll ***a*** for each of the seven sites sampled in this study (Table 5) with the relevant arithmetic mean chlorophyll ***a*** standard given in the 1975 Policy (EPA 1975). As there is some seasonal variation in the standards for some segments of the Bay in the policy, we have used the relevant segment standards applicable for at least three of the four seasons. On this basis the existing chlorophyll ***a*** standards have been exceeded at all seven sites in some years. The sites and the number of years out of the five possible that the relevant standards were exceeded are as follows:- Blairgowrie (4/5), Wooley Reef (2/5), Beaumaris (4/5), Sandringham (3/5), Williamstown (2/5), Werribee (5/5) and Clifton Springs (1/5).

A recent draft policy, issued for public comment, has proposed new chlorophyll ***a*** objectives for various segments of the Bay (EPA 1995). The proposed standards for chlorophyll ***a*** are annual medians and annual 90% quantile values. Direct comparisons can be made between the proposed standards and annual medians and annual 90% quantiles calculated in this report (Table 5). The annual medians and 90% quantiles for Blairgowrie, Williamstown and Werribee did not exceed the proposed concentrations for the segments in which they occur - 'General' (median <1.0 μg L^{-1}, 90% quantile <2.0 μg L^{-1}), 'Hobsons' (<2.7 and <5.0 μg L^{-1}) and 'Werribee' (<2.7 and <5.0 μg L^{-1}) segments respectively - in any year. However, there were four annual 90% quantiles for Werribee greater than 4.0 μg L^{-1}, with a maximum value of 4.93 μg L^{-1} which is just lower than the 5.0 μg L^{-1} standard. Furthermore, the annual median (< 1.0 μg L^{-1}) and 90% quantile (<2.0 μg L^{-1}) standards proposed for the 'General' segment of the Bay were exceeded in several years at three sites located in this segment. These sites and the number of years that the relevant standards were exceeded are as follows:- Wooley Reef (2/5 for median and 4/5 for 90% quantile), Sandringham (3/5 and 4/5) and Clifton Springs (2/5 and 3/5). Similarly, the proposed annual median (<1.5 μg L^{-1}) and annual 90% quantile (<2.5 μg L^{-1}) standards for the 'Inshore' segment were exceeded at Beaumaris in 2/5 and 4/5 of the five years respectively.

The above results show that even the proposed standards have been exceeded at four of the seven sites in either three or four of the five years. These findings, and the fact that toxic and nuisance phytoplankton blooms have already occurred in Port Phillip Bay over recent years, suggest that the proposed concentrations for chlorophyll ***a*** and present management strategies to minimise eutrophication both require re-examination.

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