ENVIRONMENT REPORT

GIPPSLAND LAKES BLUE-GREEN ALGAE MONITORING PROGRAM JULY – DECEMBER 2008

Report to the Gippsland Task Force

Task RCIP EG 0809 06. 096

Publication 1291 July 2009

EXECUTIVE SUMMARY

This report presents the finding of the Gippsland Lakes Taskforce-funded blue-green algae monitoring program for July to December 2008. The program monitors the Gippsland Lakes foreshore for toxic cyanobacteria (blue-green algae) and provides scientific advice to inform management decisions as part of regional contingency plans for blue-green algae blooms in the Gippsland Lakes.

The program includes:

- monitoring for the toxic cyanobacterium *Nodularia spumigena* at four key shoreline sites on a weekly basis
- monitoring for the presence or absence of phytoplankton species in shoreline samples from the Gippsland lakes
- basic water quality monitoring
- compiling a comprehensive list of Gippsland Lakes phytoplankton (including toxic species)
- providing weekly reports of algal species and cell counts to EPA and DSE.

The information gathered during the project provided an opportunity to assess the presence of other species of algae and monitor the water quality factors associated with individual species, providing an integrated data set to support future algal bloom modelling. Seasonal effects of temperature, flood and salinity appear to be the major factors influencing water quality and algal species prevalence at the four monitored sites.

Following the bloom of *Synechococcus* sp. in summer and autumn 2007–08, weekly monitoring continued at the foreshore sites from July to December 2008. Cyanobacteria biovolumes remained low throughout the period and did not approach the *Guidelines for Managing Risks in Recreational Water* (NHMRC 2008) trigger levels for human exposure.

A bloom of the predatory dinoflagellate *Noctiluca scintillans* unprecedented in its extent in the Gippsland Lakes occurred from October to December 2008. *Noctiluca* feeds on other microalgae and the bloom occurred in response to the large amount of food available from the previous *Synechococcus* sp. bloom, warm water temperature and increased salinity.

Water temperature (measured at 50 cm depth) ranged from 8 °C to 24 °C, reflecting both seasonal change and local conditions, such as sheltered, shallow-water sites.

Despite one significant rainfall event in November 2008, salinity levels varied little (25 to 32 ppt), with the exception of Jones Bay (4 to 26 ppt). pH levels were also within a more normal range compared to levels recorded during the previous *Synechococcus* sp. bloom.

Dissolved oxygen (DO) levels were good throughout the year, averaging 94 to 95 per cent saturation at all sites (except the Warm Holes) and peaking at 142 per cent at Duck Arm in late December 2008. There was no indication of significant oxygen consumption at the foreshore sites (to two metres deep), following the extensive *Synechococcus* sp. bloom.

Warm Holes #2 is poorly flushed and can experience fish death events thought to be associated with very low oxygen concentration conditions. DO saturation at Warm Hole #2 averaged 75 per cent and reached a minimum 38 per cent on one occasion throughout the year. No fish death events were recorded in the Warm Holes during the monitoring period.

Turbidity levels (Secchi depth) gradually improved throughout the period, with Secchi depths around 1.6 m regularly recorded. The *Noctiluca* bloom reduced light penetration to zero on occasions at Duck Arm but, by the end of December 2008, Secchi depth had increased to 0.9 m. Minor fluctuations were caused by intermittent localised blooms of benign diatom and dinoflagellate species.

The toxic dinoflagellate *Gymnodinium catenatum,* initially recorded at Lakes Entrance (Smith 2007) and subsequently in low abundance at Newlands Arm (EPA 2009), was not detected during the monitoring period.

BACKGROUND

The Gippsland Lakes are a series of large estuarine lakes situated in the south-eastern corner of Australia, about 200 km east of Melbourne. These coastal lagoons are separated from Bass Straight by a system of sandy barriers (Figure 1A). The three major lakes (Wellington, Victoria and King) are approximately 69 km in length and 10 km wide; they have surface areas of 148, 75 and 98 km^2 respectively, giving a total area of 364 km^2. The lakes are generally shallow, with Lake Wellington in the west having an average depth of 2.6 m, Lake Victoria 4.8 m and Lake King 5.4 m (Webster et al. 2001).

At the eastern end of the Gippsland Lakes is a channel (Lakes Entrance), which has been maintained open since its construction in 1889. This entrance to the ocean maintains a strong salinity gradient running east to west along the Gippsland Lakes system, which is relevant to the distribution of algal species.

The six major rivers drain a total catchment area of 20,600 km^2, which represents about nine per cent of the total land area of Victoria (Webster et al. 2001).

The Gippsland Lakes form an important ecosystem in terms of environmental, economic, cultural and social values. Its wetlands are listed under a number of international convention treaties, including the Ramsar Convention, the Japan–Australia Migratory Bird Agreement (JAMBA) and the China–Australia Migratory Bird Agreement (CAMBA) (Anon 2002). The Gippsland Lakes are recognised as an important nursery ground for a diverse selection of aquatic species, some with commercial importance (Rigby 1982; Ramm 1983; Coutin et al. 1996).

WHY DO WE MEASURE BLUE-GREEN ALGAE?

A number of reviews have identified the major environmental pressures that pose a threat to the health of the Gippsland Lakes ecosystem (Harris et al. 1998; Webster et al. 2001). The catchment surrounding the Gippsland Lakes has undergone significant change since the settlement of Europeans in the mid-19th century. Clearing of forests to make way for agriculture, livestock, mining and urbanisation have resulted in increased loads of nutrients, toxicants and sediment washed from the catchment, through the rivers and into the lakes. The permanent opening to the ocean of the Gippsland Lakes established in 1889 has changed pre-European conditions, establishing a more saline environment, especially at the eastern end of the lakes.

This has resulted in a substantial alteration of the lakes environment (Webster et al. 2001). Of considerable environmental and economic concern is the increased frequency and intensity of cyanobacterial blooms. Cyanobacteria, commonly called blue-green algae, are representative of the earliest fossilised records of life on earth. Cyanobacteria can be considered a type of photosynthetic bacterium — as with higher plants, they contain chlorophyll-*a*. Most blue-green algae are restricted to fresh water but a few have adapted to estuarine or marine systems. Some species of blue-green algae produce toxins that are known to be hazardous to humans and other life. Under favorable environmental conditions a toxic species of blue-green algae may increase in cell numbers to a point where they dominate other species in the surrounding environment. This is termed a blue-green algal bloom.

Nodularia spumigena is a cyanobacterium commonly found in estuarine conditions such as those in the Gippsland Lakes. It is toxic and causes poisoning in the liver of humans, and has caused death in domestic and marine animals (Davies et al. 2005). Blooms of *Nodularia* have increased in frequency in the Gippsland Lakes. The last intensive bloom in 2001–02 prompted the issuing of warnings against contact with lake water, eating seafood from the Gippsland Lakes and recreational fishing. Commercial fishing was also banned until the bloom had disappeared. To provide advice on potentially hazardous algal blooms, EPA, with the support of DSE and the Gippsland Lakes Task Force, began weekly algal bloom monitoring in late 2005.

WHAT WAS MONITORED?

Four sites were monitored weekly for water quality measures and algal composition from 1 July to 31 December 2008. These four sites – the Warm Holes, Jones Bay, Newlands Arm and Duck Arm (see Figures 1A and 1B) – were chosen based on the historical incidence of blue-green algal blooms or fish deaths and proximity to populated area. For example, the Warm Holes site is located near the centre of the township of Lakes Entrance and is prone to fish deaths.

Figure 1A: Location of sampling sites – all sites.

Figure 1B: Location of sampling sites – close-up of the Warm Holes.

Water quality measures

Weekly measurements of temperature, salinity, dissolved oxygen and pH were carried out using a Hydrolab Quanta handheld water quality meter, calibrated prior to each day's sampling. Light penetration was measured using a 20 cm diameter Secchi Disk.

Algal sampling

Plankton were collected using a 20 µm phytoplankton net and 250 mL or 1 L sample bottles. Samples were preserved in Lugol's solution for counting (Sedgewick-Rafter chamber and haemocytometer) and species were identified using a Zeiss 25 Axiovert inverted microscope.

WHAT DID WE FIND?

Water quality measures

Graphs of water quality at the four monitored sites for the 6 months (July 2008 - December 2008) are shown in Figures 2 to 5. Table 1 summarises the physicochemical data (see Appendix 1) for this period. The dominant feature is the effect of algal blooms on water clarity. A gradual increase in Secchi depth caused by decline of the *Synechococcus* sp. bloom is seen at Newlands Arm and Duck Arm (Figures 4 and 5) while an extensive bloom of the non-photosynthetic dinoflagellate *Noctiluca scintillans* resulted in a period of increased turbidity (Duck Arm Secchi depth of 0 m) from October to December 2008.

Surface temperature ranged between a minimum of 8.3°C in July 2008 and maximum of 24 °C in December 2008. All sites reached an early peak in November, reducing by 3 to 5°C in subsequent weeks before increasing again by the end of the monitoring period (December 2008).

Salinity varied little at lake sites Newlands Arm and Duck Arm (Figures 4 and 5) and showed little if any response to localised rainfall events (Figure 6). For example, 137 mm rainfall at Bairnsdale in November (about 19 per cent of the annual mean) (BoM, 2008) had no apparent overall effect on salinity across the Lakes. By contrast, the Jones Bay site (Figure 3) is directly impacted by flow from the Mitchell River and showed considerable variability. In addition to the November rain event, low salinity levels occurred in the absence of rainfall (for example, early September). However, this site may not be representative of the overall bay salinity due to physical constraints such as shallow water depth and proximity to shoreline and as such subject to residual fresh water run off.

Warm Hole #2 (Figure 2) is least affected by freshwater inflow from lake sources due to its proximity to ocean influences that include tidal flow and flow through palaeo-channels associated with the pre-1889 ocean entrance. River flow is a major determinant of salinity levels in the broadwater areas of the Gippsland Lakes, but may have limited immediate impact at the foreshore sites (other than Jones Bay) except under flood conditions.

Dissolved oxygen (DO) levels were generally good throughout the six month period. Newlands Arm, Duck Arm and Jones Bay averaged 94 to 95 per cent saturation and Warm Hole #2 averaged 73 per cent. Jones Bay showed a slight peak in October due to spring algal growth. Duck Arm levels reduced briefly during November at the height of the *Noctiluca scintillans* bloom and recovered through December as photosynthetic species regained dominance. Warm Holes #2 DO levels fluctuated during this period (minimum of 38 per cent recorded at the end of December), however this type of fluctuation is common at shallow sediment-rich sites, such as the Warm Holes, during warmer months. There was no prolonged period of critically low dissolved oxygen and there were no reports of fish death events at any sites during this period.

The pH was fairly stable throughout the monitoring period, averaging 7.6 across the four sites with maximum levels of 8.3 to 8.4 at Duck and Newlands Arms, compared with pH 9.2 recorded at Newlands Arm (December, 2007) during the previous algal bloom, indicating limited algal activities overall.

Table 1. Physicochemical ranges for the four foreshore monitoring sites from July to December 2008

Site / Parameter	Warm Hole #2	Jones Bay	Newlands Arm	Duck Arm
Temperature (°C)	8.3–22.6	8.3–21.3	8.8–22.6	9–24
Salinity (ppt)	25–32	3.7–26	25–30	26–30
Dissolved oxygen (%)	38–95	78–114	84–108	62–142
pH	6.7–7.9	6.9–8.2	7.3–8.4	7.3–8.3
Secchi depth (cm)	Shallow site (max. 30 cm)	Shallow site (max. 30 cm)	40–160	0–130

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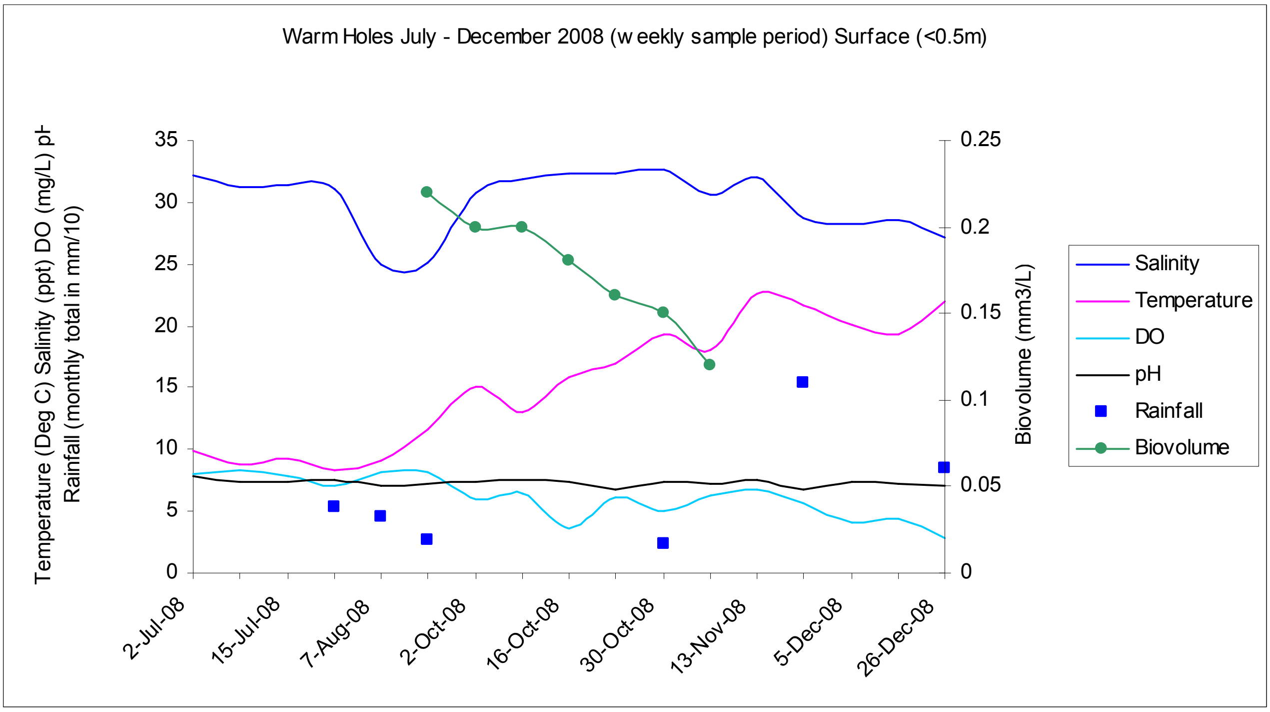

Figure 2: Warm Hole #2. July–December 2008. Salinity shows some response to September and November rainfall events (note: rainfall shown as monthly total recorded at Tambo Bluff). DO is relatively low compared to other monitored sites, possibly due to increased bacterial respiration. Biovolume of *Synechococcus* sp. remained low throughout the monitoring period.

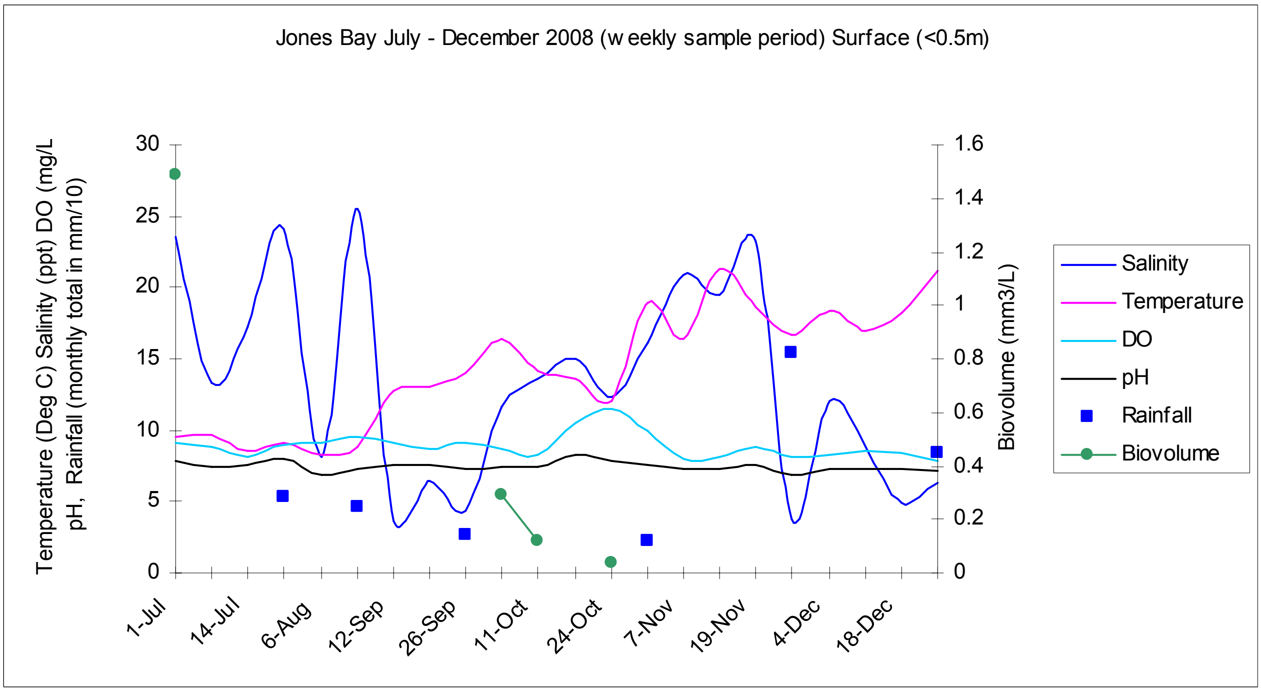

Figure 3: Jones Bay July–December 2008. Fluctuating salinity levels show response to September and November rainfall (Tambo Bluff). *Synechococcus* sp. biovolume remained low throughout the monitoring period.

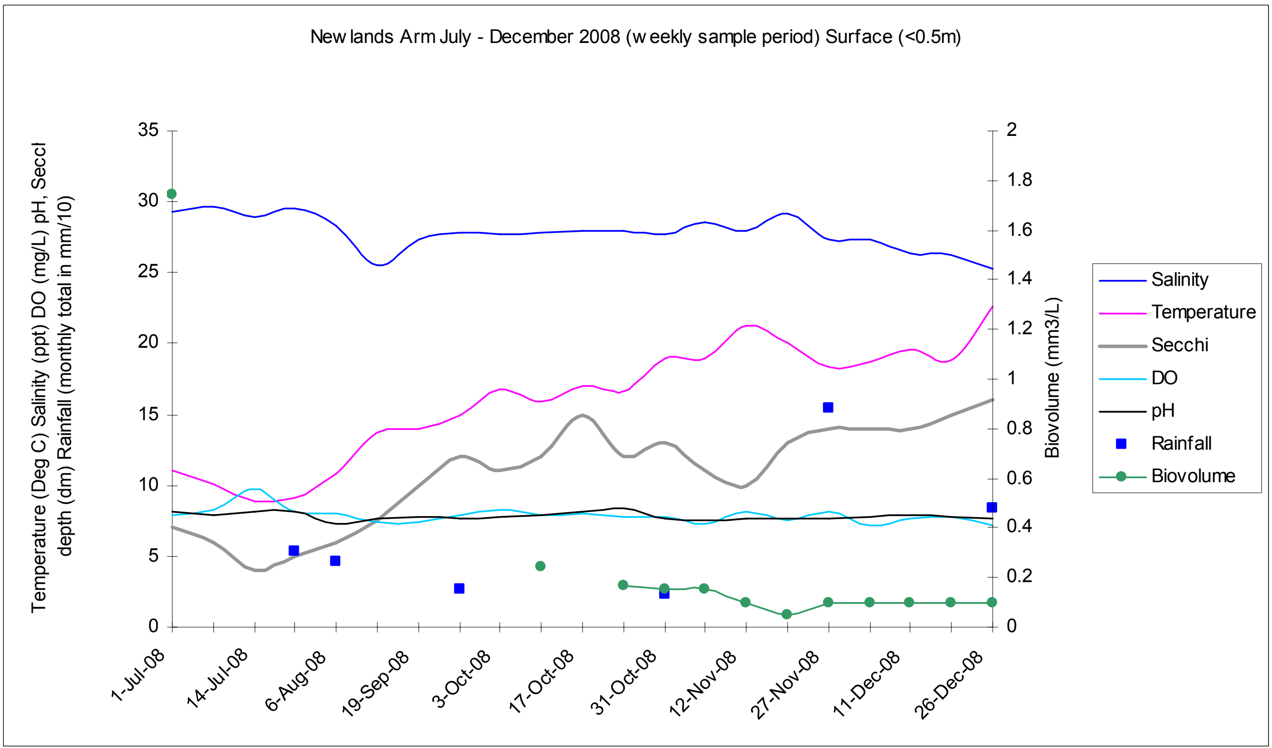

Figure 4: Newlands Arm July–December 2008. Rainfall events have limited impact on salinity. Biovolume of *Synechococcus* sp. remained low. Secchi depth increased steadily throughout the period, interrupted by *N. scintillans* bloom October–December 2008.

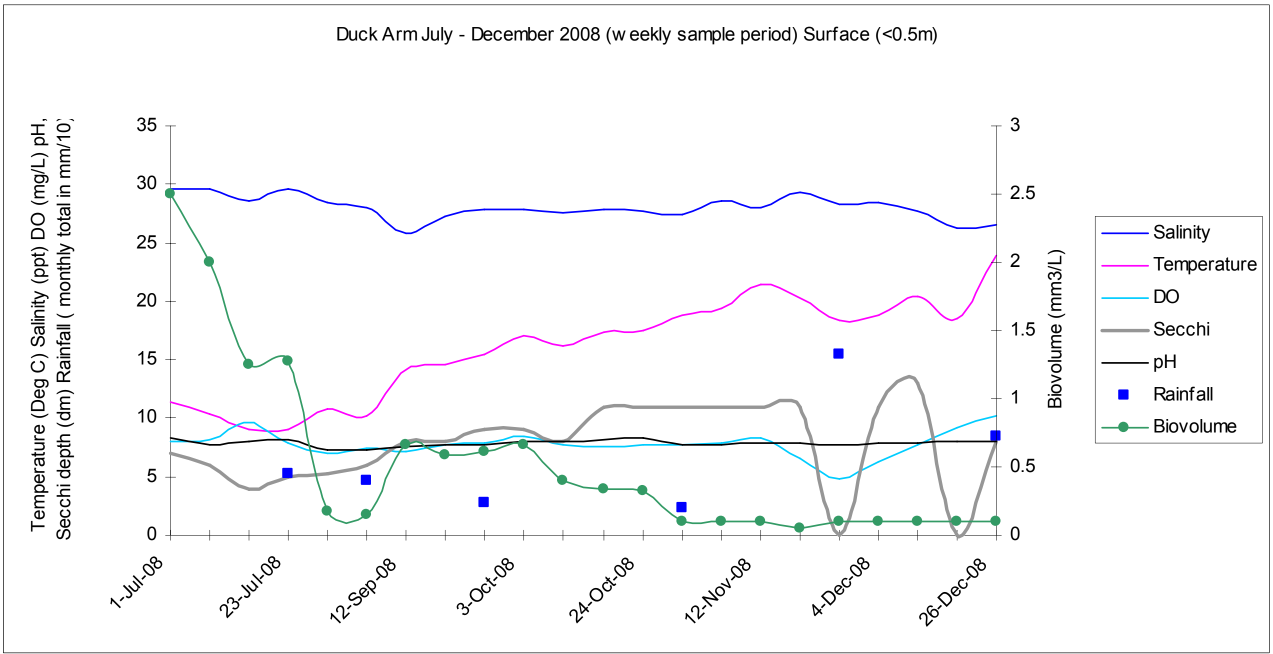

Figure 5: Duck Arm July–December 2008. Similar pattern to Newlands Arm (Fig. 4). *Synechococcus* sp. biovolume much reduced. Secchi depth and DO affected by *N. scintillans* bloom October–December 2008.

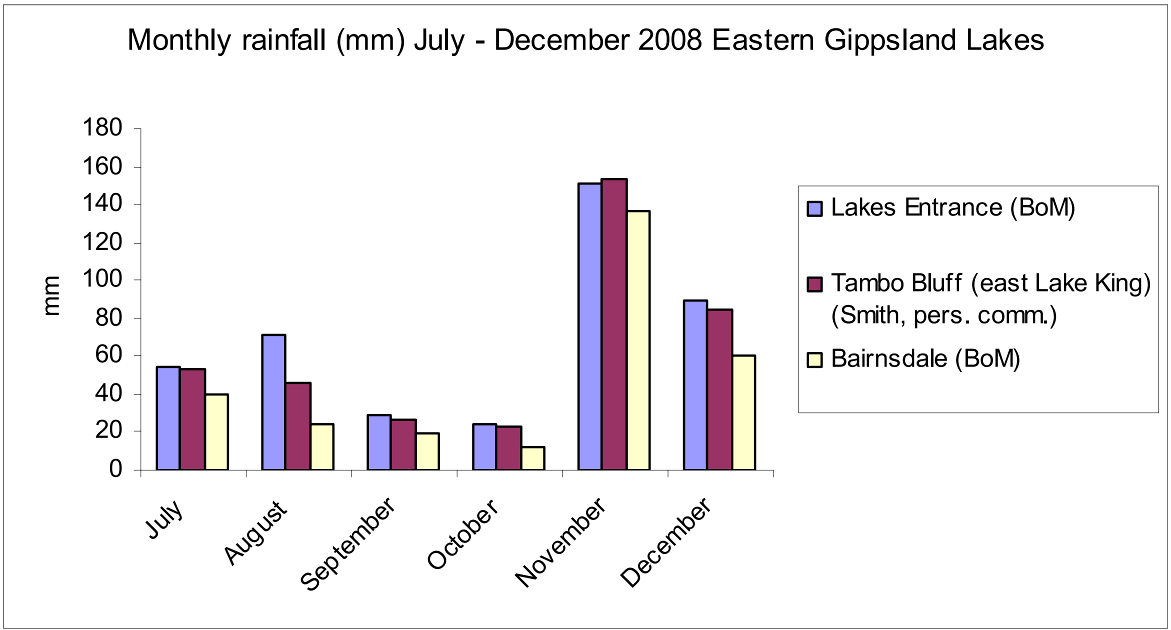

Figure 6: Monthly rainfall July–December 2008. Rainfall increases towards the east. Care must be exercised interpreting monthly data. For example, 68 per cent of the September total rainfall at Lakes Entrance occurred on the 23rd day of the month (BoM), resulting in a pronounced salinity drop at the Warm Holes (Fig. 2).

Algae community measures

Phytoplankton diversity

Species diversity is a useful and widely accepted measurement of environmental health (Magurran 2003). High diversity is considered important for healthy ecosystem functioning and is characterised by changes in composition. Low diversity is symptomatic of low rates of change (Reynolds 2006) that may be linked to domination by one or a few species (for example, during an algal bloom). Diversity is a combination of species richness (number of species found) and abundance (number of individuals of a species).

As quantitative data (cell counts) were only collected for the dominant and known toxic cyanobacteria species during bloom periods, it was not possible to calculate a diversity index for all microalgae species found. Presence/absence data was compiled for all microalgae found at the four foreshore sites (Appendix 2). Species richness (Figure 7) indicates normal or expected change in composition. An increase in all species can be seen in spring, which results in an increase in zooplankton and other predators such as *N. scintillans*. Diatoms are rapidly grazed down in preference to less palatable and harder-to-catch motile dinoflagellates. Both groups recover as zooplankton predators themselves become prey species and the *N. scintillans* bloom collapses.

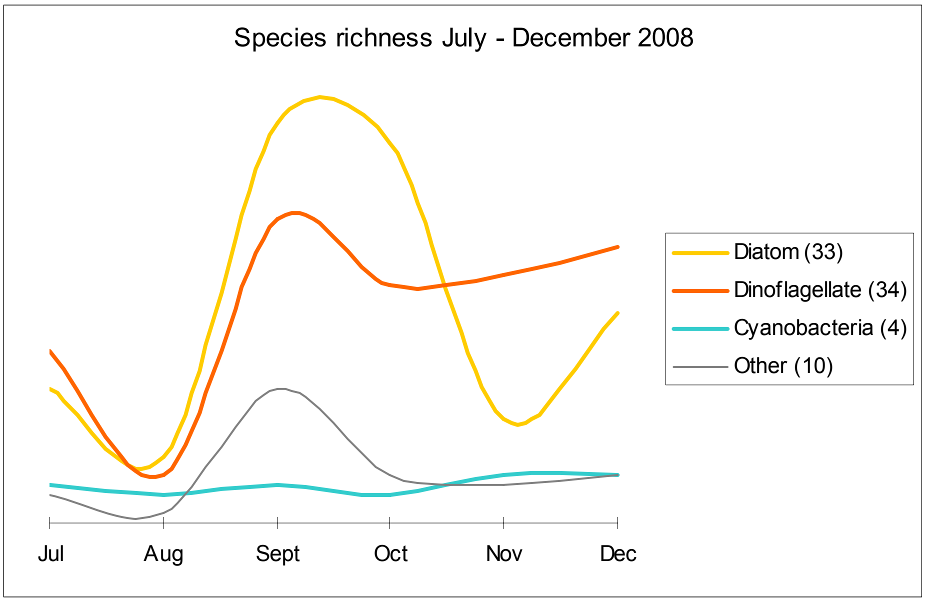

Figure 7: Species richness calculated from presence/absence data (Appendix 2, number of taxa indicated in bracket). Note that, for ease of interpretation, monthly averages have been plotted using a smoothed line. Increased microalgal activity in spring is evident. Diatoms are grazed down by zooplankton in October/ November, less palatable motile dinoflagellates are less affected. All species become potential prey to *Noctiluca.* Few cyanobacteria species present.

Cyanobacteria

Nodularia spumigena (Figure 8) is a toxic filamentous species that can form extensive surface scums and has been identified as the primary harmful algal bloom (HAB) species in the Gippsland Lakes (Chessman 1988; Webster *et al*. 2001). *Nodularia spumigena* was absent from all sites during the monitoring period, probably due to the effects of low temperature during winter, relatively high salinity levels for most of the period, and light and nutrient competition from *Synechococcus* sp.

Figure 8: Filaments of *N. spumigena* X200, Lake King 2002. §

Synechococcus sp. (Gippsland Lakes) (Figure 9) is a small (1–3.5 µm) spherical, non-filamentous cyanobacterium with an apparent salinity tolerance range from marine conditions (around 36 ppt) to approximately 5 ppt. *Synechococcus* species are major primary producers, ubiquitous in the marine environment, capable of acquiring nutrients at very low (submicromolar) concentrations and highly adapted to a range of light environments (Waterbury *et al*. 1986).

The species dominated the algal flora during summer and autumn 2007–08 but abundance had declined significantly by July 2008 and remained low throughout the monitoring period. There was little growth response to increased temperature, which suggests nutrient may have been the primary factor limiting growth.

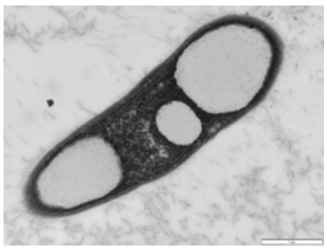

Figure 9. *Synechococcus* sp. TEM longitudinal section (Image © R Webb).

Few other cyanobacteria species were present and are reported in Appendix 2.

Dinoflagellates

Dinoflagellates are single-celled algae ranging in size from approximately 8 to 200 μm (*Noctiluca* ≤ 2 mm). They have a two tail-like structure (flagella) used for motion in the water column. Photosynthetic species are commonly coloured golden-brown due to photosynthetic pigments and predator (phagotrophic) or parasitic species are clear or coloured by pigments acquired during prey consumption. They occur in all aquatic habitats, but the majority of species are found in marine and brackish environments.

Approximately 60 of the 2000 species that exist are toxic and are the dominant algal group responsible for the phenomena known as red-tides. The toxic species share several characteristics. Most are photosynthetic coastal/estuarine inhabitants that produce a benthic resting stage and blooms of only one species (monospecific). The toxic species produce a range of bioactive substances (toxins), some of which can cause serious illness or death in humans, aquatic mammals, fish, birds and invertebrates. There is no historical or recent evidence that directly implicates dinoflagellates in a toxic event in the Gippsland Lakes.

Several potentially noxious species were recorded in low concentration at the foreshore sites, including *Dinophysis acuminata* (which causes Diarrhetic Shellfish Poisoning (DSP) (Figure 10), *Karenia* species (neurotoxic shellfish poisoning – NSP, Figure 11), *Karlodinium* species (ichthyotoxins) and *Noctiluca scintillans* (high ammonia production, Figure 12).

An extensive bloom of *Noctiluca scintillans* occurred from October to December 2008, probably in response to warmer temperature and an abundance of prey species, predominantly *Synechococcus* sp. *N. scintillans* is a predatory dinoflagellate with a distinctive large floating bladder. It feeds voraciously on anything it comes into contact with, including microalga and fish eggs. It is non-toxic but produces large amounts of ammonia, potentially causing mortality of benthic organisms and providing a source of nitrogen for cyanobacteria and other dinoflagellates. The species produces a light-flash when physically disturbed. Blooms of this species have been increasing in recent years in southern Australia due to ocean warming and it has become one of the most common red-tide species in Australian waters (Hallegraeff 2002).

Other commonly occurring non-toxic species included *Scrippsiella trochoidea, Prorocentrum triestinum* (*redfieldii*, Figure 13) and *Ceratium furca* (Figure 14).

Figure 10: *Dinophysis acuminata* X400. §

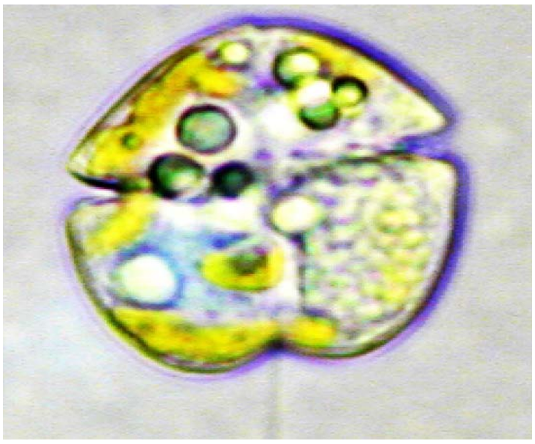

Figure 11: *Karenia* sp. X400.

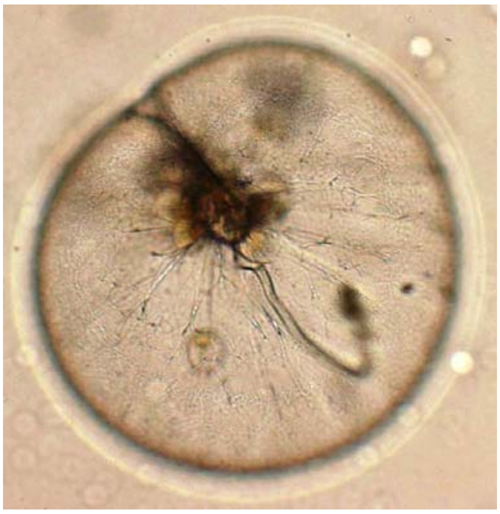

Figure 12: *N. scintillans* single cell, approximately 1.5 mm diameter. §

Figure 13: *P. triestinum* X400. §

Figure 14: *C. furca* X400. §

Diatoms

Diatoms are single-celled and often chain-forming golden-brown microalgae up to 2 mm in size. They produce finely structured and often highly ornamented silica cell walls and are known colloquially as the 'grasses of the sea', due to their significance as primary producers in the aquatic food web. Like their terrestrial counterparts, they commonly experience accelerated growth (blooms) in spring and autumn.

Very few diatom species are toxic. Arguably the most significant toxic genus is *Pseudo-nitzschia*, with some species producing domoic acid, the neurotoxic compound responsible for amnesic shellfish poisoning (ASP).

Pseudo-nitzschia species are commonly found in the Gippsland Lakes and some are identifiable using standard light microscope. However, proper identification of the toxic species requires electron microscopy. Two species are considered the most likely cause of ASP, *P. multiseries* and *P. australis* . Both are found in south-east Australian waters and traces of domoic acid were found in Lakes Entrance scallops in 1992 (Zann & Sutton 1996). No toxic species were found at foreshore sites during the monitoring period.

Chaetoceros convolutus is a chain-forming species that has long, hollow, barbed spines extending from the corners of the cell. These spines can break off in fish gills and cause suffocation or secondary infection that can lead to fish death. *C. convolutus* has been found at Lakes Entrance in previous years but was not present in foreshore samples during the monitoring period.

Species commonly found included *Skeletonema costatum* and *Nitzschia* sp. (Figures 15 and 16).

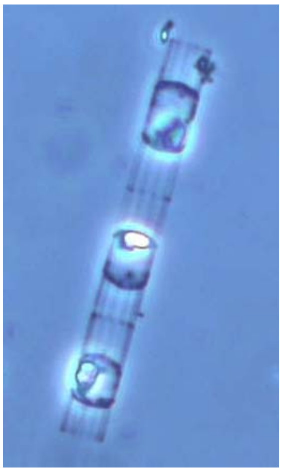

Figure 15: *S. costatum* X400 (phase contrast). §

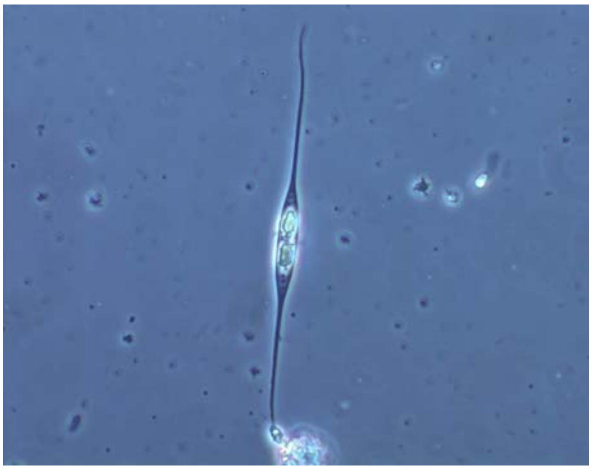

Figure 16: *N. longissima* X400 (phase contrast). §

DISCUSSION

As noted in a previous report (EPA 2009), some water quality parameters measured at the four sites did not meet the objectives set out in the *State Environment Protection Policy (Waters of Victoria) – Schedule F3 – Gippsland Lakes and Catchment segments* (SEPP WoV) for part of the year. This was attributed to the *Synechococcus* sp. Bloom.

During the present monitoring period, water quality steadily recovered from the effects of this bloom as evidenced by the increased Secchi depth and lower pH and DO saturation levels.

This recovery was interrupted by an unprecedented bloom of the predatory dinoflagellate *N. scintillans,* which had an adverse effect on turbidity and visual amenity at some sites. Regeneration of nutrients, in particular the release of ammonia by *N. scintillans*, may lead to further localised dinoflagellate or cyanobacteria algal blooms in areas of dense *Noctiluca* accumulation.

Short periods of low DO occurred infrequently throughout the monitoring period (measured at 50 cm water depth) and were likely related to the ongoing breakdown of the *Synechcocccus* sp. bloom and the effects of the *Noctiluca* bloom on photosynthetic species and bacterial activity.

ACKNOWLEDGEMENTS

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Jonathan Smith conducted sample collection and analysis and provided micrographic images marked §.

Dr Rick Webb University of Queensland provided TEM images.

REFERENCES

Anon. 2002. *Gippsland Lakes Future Direction and Actions Plan*. Department of Natural Resources and Environment, pp. 1–38.

Bureau of Meterology, 2008. (www.bom.gov.au/climate/dwo/200811/html/IDCJDW3004.200811.shtml)

Coutin P, Walker S, Morison A (ed.) 1996. *Black bream 1996*. Assessment Report Number 14. Bay and Inlet Fisheriesand Stock Assessment Group. Marine and Freshwater Resources Insititute, Queenscliff, Fisheries Victoria, pp. 1–83.

Chessman BC 1988. *Weather, Water Quality and Algal Blooms in the Gippsland Lakes*. Gippsland Lakes Algal Bloom Seminar. Ministry for Conservation, Forests and Lands, Victoria.

Davies WR, Siu WH, Jack RW, Wu RS, Lam PK, Nugegoda D 2005. Comparative effects of the blue-green algae *Nodularia spumigena* and a lysed extract on detoxification and antioxidant enzymes in the green-lipped mussel (*Perna viridis*). *Marine Pollution Bulletin* 51, 1026–33.

EPA 2009. *Gippsland Lakes Blue-Green Algae Monitoring Program 2007 - 08*. Report to the Gippsland Task Force. Publication No. 1272 Environment Protection Authority, Victoria.

Hallegraeff, GM 2002. *Aquaculturists' Guide to Harmful Australian Microalgae*. University of Tasmania, Hobart.

Harris G, Batley G, Webster I, Mollow R, Fox D 1998. Review of Water Quality and Status of the Aquatic Ecosystems of the Gippsland Lakes. In *CSIRO Gippsland Lakes Environmental Audit*, prepared for the Gippsland Coastal Board, pp. 1–34.

Magurran AE 2003. *Measuring Biological Diversity*. Blackwell Publishing UK, p. 153.

NHMRC (National Health and Medical Research Council). 2008. *Guidelines for Managing Risks in Recreational Water*. NHMRC, Canberra.

Phlips EJ, Badylak S, Lynch TC 1999. Blooms of the picoplanktonic cyanobacterium *Synechococcus* in Florida Bay, a subtropical inner-shelf lagoon. *Limnology & Oceano*graphy 44(4) 1166 - 1175.

Ramm D 1983. *An ecological survey of postlarval and juvenile fish in the Gippsland Lakes (Victoria)*, Gippsland Regional Environmental Study Ministry for Conservation, Victoria Report, pp. 1–25.

Reynolds, CS 2006. *Ecology of Phytoplankton*. Cambridge University Press, New York. p. 535.

Rigby BA 1982. An ecological study of the Estuarine Fish Assemblage in the Gippsland Lakes. Internal Report No. 3. Marine Science Laboratories, Ministry for Conservation, pp. 1–55.

Smith J L 2007. First record of dinoflagellate *Gymnodinium catenatum* Graham (1943) from Lakes Entrance, Gippsland Lakes, Australia. *Harmful Algal News* No. 34, Intergovernmental Oceanographic Commission of UNESCO, October 2007.

Waterbury JB, Watson` SW, Valois FW, Franks, DG 1986. Biological and Ecological Characterization of the Marine Unicellular Cyanobacterium Synechococcus. In: T. Platt and W. Li (eds.), Photosynthetic Picoplankton. *Can. J. Fish. Aquat. Sci. Bull*. 214: 71 - 120.

Webster I, Parslow JS, Grayson RB, Molloy RP, Andrewartha J, Tan KS, Walker SJ, Wallace BB 2001. *Gippsland Lakes Environmental Study Assessing Options for Improving Water Quality and Ecological Function*. Final Report, Gippsland Coastal Board, CSIRO, November 2001, pp. 1–84.

Zann LP, Sutton, D (Eds) 1996. *State of the Marine Environment Report for Australia: State and Territory Issues – Technical Annex 3*. Department of the Environment, Sport and Territories, Canberra.

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APPENDIX 1: PHYSIOCHEMICAL DATA JULY – DECEMBER 2008

Table 2: Warm Hole #2 water quality data

Date	Time	Cloud/10	Wind kts	Air °C	RH%	Water °C	pH	Sc ms/c	Sal ppt	DO mg/l	DO %	Bio mm³/L
2-Jul-08	8.45	5		12.4	57	9.92	7.86		32.2	8.03	89	
9-Jul-08	8.50	8		6.0	78	8.80	7.37		31.3	8.30	87.7	
15-Jul-08	8.30	0		8.0	74	9.21	7.38		31.4	7.82	83.5	
23-Jul-08	8.30	1		7.3	75	8.31	7.57		31.1	7.11	73.2	
7-Aug-08	9.00	9		8.5	75	9.16	7.10		25.0	8.19	83.3	
23-Sep-08	8.35	0	SW 10	9.0	65	11.68	7.16	40.3	25.2	8.17	89.0	0.22
2-Oct-08	7.50	0	SW 5	15.0	69	15.10	7.45	47.9	30.7	6.00	72.2	0.20
8-Oct-08	8.15	9	SW15	11.5	63	13.02	7.46	49.8	31.9	6.50	75.3	0.20
16-Oct-08	8.20	9	SW2-3	12.0	75	15.84	7.39	50.1	32.3	3.55	43.5	0.18
23-Oct-08	9.00	2	SW0-1	10.5	73	17.00	6.70	50.1	32.4	6.16	76.9	0.16
30-Oct-08	8.15	5	0	17.5	79	19.31	7.43	50.4	32.7	5.00	66.3	0.15
6-Nov-08	7.50	8	SW 5			18.05	7.18	47.5	30.6	6.20	79.8	0.12
13-Nov-08	7.50	5	0	19.0	67	22.64	7.61	49.1	32.0	6.73	94.7	
28-Nov-08	8:15	10	0	15.8	80	21.71	6.76	44.6	28.7	5.59	76.4	
5-Dec-08	8:45	3	0	20.0	71	20.16	7.39	44.2	28.3	4.04	52.9	
11-Dec-08	7:30	9	0	13.6	81	19.31	7.26	44.6	28.6	4.36	56.4	
26-Dec-08	8:00	1	0	16.5	79	22.00	7.13	42.4	27.1	2.78	37.7	

Table 3: Jones Bay water quality data

Date	Time	Cloud/10	Wind kts	Air °C	RH%	Water °C	pH	Sc ms/c	Sal ppt	DO mg/l	DO %	Bio mm3/L
1-Jul-08	10:40	8		11.9	63	9.60	7.80		23.60	9.16	95.2	1.49
8-Jul-08	8:40	1		6.4	63	9.62	7.49		13.30	8.90	85.1	
14-Jul-08	9:15	9		11.5	56	8.54	7.52		17.30	8.14	78.0	
23-Jul-08	10:05	4		8.9	64	9.08	8.06		24.20	9.00	90.1	
6-Aug-08	9:15	1		12.0	77	8.29	6.89		8.09	9.16	81.8	
13-Aug-08	10:10	2		9.8	60	8.89	7.24		25.50	9.53	96.5	
12-Sep-08	9:10	10		18.0	46	12.71	7.62		3.67	9.14	88.9	
19-Sep-08	9:10	7	N 2	20.0	52	12.99	7.63	11.46	6.43	8.69	86.4	
26-Sep-08	8:20	8	NE 2	19.0	46	13.99	7.30	7.93	4.34	9.13	90.9	
3-Oct-08	8:35	1	NE 2	15.0	84	16.35	7.46	19.80	11.70	8.76	96.1	0.29
11-Oct-08	8:20	0	0	14.5	74	14.16	7.43	22.80	13.60	8.28	87.5	0.12
17-Oct-08	8:30	1	0	13.0	75	13.56	8.21	25.00	15.00	10.45	109.4	
24-Oct-08	8:30	10	NW 1	14.0	63	12.10	7.80	20.90	12.30	11.46	113.8	0.04
31-Oct-08	8:55	9	NW 5-10	19.0	59	18.90	7.59	26.60	16.10	9.93	119.0	
7-Nov-08	8:00	9	0	15.5	68	16.35	7.34	33.70	20.90	8.01	93.5	
12-Nov-08	8:15	1	0	21.5	62	21.25	7.27	31.50	19.50	8.08	102.7	
19-Nov-08	8:30	10	WNW 2	18.0	81	18.58	7.53	37.10	23.30	8.82	108.9	
27-Nov-08	8:10	2	SE 2	21.6	66	16.62	6.93	6.92	3.76	8.12	86.2	
4-Dec-08	8:00	2	0	15.5	58	18.34	7.25	20.30	12.00	8.31	94.9	
11-Dec-08	8:35	9	0	16.4	73	16.93	7.33	15.30	8.83	8.57	93.7	
18-Dec-08	9:30					18.24	7.28	8.77	4.85	8.35	91.4	
26-Dec-08	9:10	5	0	19.0	51	21.18	7.18	11.10	6.27	7.80	91.7	

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Table 4: Newlands Arm water quality data

Date	Time	Cloud/10	Wind kts	Air °C	RH%	Water °C	pH	Sc ms/c	Sal ppt	DO mg/l	DO %	Bio mm3/L	Secchi dm
1-Jul-08	11:15	10		11.9	53	11.03	8.16		29.3	7.93	88.3	1.74	7.0
8-Jul-08	9:30	0		9.8	66	10.11	7.89		29.7	8.22	88.5		6.0
14-Jul-08	9:50	7		12.0	65	8.84	8.15		28.9	9.71	100.9		4.0
23-Jul-08	10:35	4		11.6	65	9.12	8.19		29.6	8.13	84.3		5.0
6-Aug-08	9:50	0		11.0	72	10.87	7.32		28.3	7.97	86.0		6.0
12-Sep-08	9:45	10		19.0	40	13.74	7.70		25.6	7.46	85.2		7.5
19-Sep-08	9:45	7	0	22.0	38	14.00	7.75	43.2	27.3	7.41	86.0		10.0
26-Sep-08	8:50	9	0	20.0	42	14.99	7.61	43.9	27.9	7.90	93.2		12.0
3-Oct-08	9:10	0	E 5	16.0	75	16.82	7.82	43.5	27.7	8.26	101.0		11.0
11-Oct-08	8:50	0	E 2	14.5	64	15.91	7.93	43.8	27.8	7.93	95.0	0.24	12.0
17-Oct-08	9:10	0	SW 0-2	15.0	55	16.99	8.14	43.9	27.9	8.04	98.0		15.0
24-Oct-08	9:00	9	NW 1	15.5	55	16.69	8.38	43.9	27.9	7.83	94.6	0.17	12.0
31-Oct-08	9:35	5	SW 8-10	20.0	53	18.92	7.66	43.5	27.8	7.80	100.4	0.15	13.0
7-Nov-08	8:30	9	0	15.0	66	18.91	7.52	44.6	28.5	7.33	94.3	0.15	11.0
12-Nov-08	8:50	0	0	22.0	52	21.21	7.60	43.6	27.9	8.10	108.3	0.10	10.0
19-Nov-08	9:00	10	0	19.0	65	20.03	7.67	45.5	29.2	7.57	99.7	0.05	13.0
27-Nov-08	8:45	1	0	20.6	54	18.32	7.67	43.0	27.4	8.17	104.0	0.10	14.0
4-Dec-08	8:40	1	0	13.5	57	18.66	7.73	43.0	27.4	7.15	90.3	0.10	14.0
11-Dec-08	9:05	9	NE 5	19.5	59	19.57	7.84	41.5	26.4	7.64	98.1	0.10	14.0
18-Dec-08	10:15					18.88	7.72	41.4	26.3	7.72	97.7	0.10	15.0
26-Dec-08	10:05	5	0	26.0	49	22.61	7.63	39.8	25.3	7.13	96.7	0.10	16.0

Table 5: Duck Arm water quality data

Date	Time	Cloud/10	Wind kts	Air °C	RH%	Water °C	pH	Sc ms/c	Sal ppt	DO mg/l	DO %	Bio mm3/L	Secchi dm
1-Jul-08	11:40	10		12.4	51	11.36	8.32		29.6	7.97	89.5	2.50	7.00
8-Jul-08	9:55	0		12.9	61	10.30	7.77		29.6	8.20	88.5	2.00	6.00
14-Jul-08	10:10	5		14.9	54	8.97	7.95		28.6	9.57	99.7	1.25	4.00
23-Jul-08	10:55	4		11.4	62	8.98	8.13		29.6	7.90	81.7	1.27	5.00
6-Aug-08	10:10	0		10.5	75	10.82	7.31		28.4	7.04	75.9	0.17	5.25
13-Aug-08	10:40	1				10.21	7.36		28.0	7.49	79.3	0.15	6.00
12-Sep-08	10:10	10		19.0	35	14.10	7.57		25.9	7.10	81.9	0.66	8.00
19-Sep-08	10:15	6	N 5	25.0	30	14.61	7.80	43.0	27.2	7.68	90.3	0.59	8.00
26-Sep-08	9:10	10	N 8-10	23.0	32	15.47	7.76	43.9	27.9	7.92	94.2	0.61	9.00
3-Oct-08	9:30	0	E 8	16.5	59	17.03	7.97	43.7	27.8	8.47	104.0	0.66	9.00
11-Oct-08	9:10	0	E 5	14.5	58	16.22	8.00	43.4	27.6	7.80	93.8	0.40	8.00
17-Oct-08	9:30	1	0	14.0	62	17.35	8.13	43.7	27.8	7.65	93.8	0.34	11.00
24-Oct-08	9:20	10	0	14.0	57	17.48	8.30	43.6	27.8	7.73	94.6	0.32	11.00
31-Oct-08	10:00	4	SW 5	19.5	54	18.85	7.66	43.1	27.5	7.77	99.7	0.10	11.00
7-Nov-08	8:50	8	E 5	16.5	73	19.45	7.70	44.7	28.6	7.91	103.0	0.10	11.00
12-Nov-08	9:10	0	0	25.0	50	21.42	7.86	43.7	28.0	8.32	111.7	0.10	11.00
19-Nov-08	9:25	10	0	18.5	65	20.33	7.88	45.6	29.3	6.50	86.2	0.05	11.00
27-Nov-08	9:10	1	0	27.0	44	18.37	7.80	44.4	28.4	4.85	62.1	0.10	0.00
4-Dec-08	9:00	1	0	15.0	50	18.80	7.81	44.4	28.4	6.34	80.8	0.10	11.00
11-Dec-08	9:30	9	NE 10	16.0	57	20.36	7.83	43.4	27.7	7.71	101.2	0.10	13.00
18-Dec-08	11:15					18.56	8.07	41.4	26.3	9.20	115.7	0.10	0.00
26-Dec-08	10:35	4	0	24.5	51	23.94	8.03	41.5	26.5	10.17	142.3	0.10	8.00

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APPENDIX 2: SPECIES LIST FROM 4 FORESHORE SITES.

Warm Holes =
Jones Bay =
Newlands Arm =
Duck Arm =
Red symbol = bloom/dominant

		July	Aug	Sept	Oct	Nov	Dec
Proteobacteria	*Beggiatoa* sp.			□			
Cyanobacteria	*Anabaena*						
	Anabaenopsis arnoldii						
	Anabaenopsis elenkinii						
	Aphanocapsa sp.		□				
	Calothrix						
	Geitlerinema						
	Limnothrix planktonica						
	Lyngbya						
	Microcystis sp.						
	Nodularia spumigena						
	Nostoc						
	Oscillatoria sancta						
	Oscillatoria sp.						
	Phormidium					□	
	Planktolyngbya						
	Planktothrix						
	cf *Prochlorococcus*						
	Spirogyra						
	Spirulina						
	Synechocystis						
	Synechococcus	■□○● (red)	○●	■○●	■○●	□■○●	■□○●
	unidentified filament						□
Dinoflagellate	*Akashiwo sanguinea*	○●		○●	○●		
	Amphidinium carterae						
	A. operculatum						
	A. poecilochroum			○●			
	A. cf *latum*						
	Amphidinium sp.			●		□	○●
	Ceratium furca	■●		○●	○●	○●	□○●
	C. fusus	○					
	C. horridum						
	C. tripos			○			
	C. trichocerus						
	cf Cochlodinium sp.						
	Coolia cf *monotis*						■
	cf *Cryptoperidiniopsis* sp.						
	Dinophysis acuminata		□	□○●	□○●	○	■
	D. caudata						
	D. fortii						
	D. rotundata						

		July	Aug	Sept	Oct	Nov	Dec
Dinoflagellate	*D. tripos*						
	Diplopsalis sp.					○	○●
	Diplopsalis lenticula			○			
	Gonyaulax polygramma						
	Gyrodinium sp.	□				■	
	Gyrodinium spirale					○	○
	Gymnodinium sp.	○					○●
	Gymnodinium aureolum				●		
	G. catenatum						
	G. impudicum						
	Heterocapsa rotundata	■			○	□	
	H. triquetra	■□	□●	□○●	○●		
	Karenia sp.	■					○
	K. cf *asterichroma*						●
	K. longicanalis						
	K. mikimotoi						
	K. papillionaceae						
	K. umbella						
	Karlodinium australe						
	K. micrum			○●	■○	○	●
	Kryptoperidinium foliaceum						□
	Nematodinium armatum			○		○	
	Noctiluca scintillans		□		○●	○●	○●
	Oblea cf *rotunda*	■		□○●	■□●		
	Ostreopsis lenticularis			○●			
	Oxyphysis oxitoxoides			○●	○	○●	○●
	Peridinium inconspicuum						
	Peridinium quinquecorne			○●			
	Peridinium sp.					■	■
	Pheopolykrikos hartmanii						
	Polykrikos kofoidii			○	○		
	P. schwartzii						
	Prorocentrum gracile			●		○●	
	P. lima						
	P. micans						
	P. minimum		□	□○●	□○	○●	○●
	P. rhathymum				■		
	P. sigmoides						
	P. triestinum/redfieldii					○●	○●
	Protoceratium reticulatum						○
	Protoperidinium bipes	■				○●	
	P. conicum						
	P. oblongum						
	P. pallidum						
	P. pedunculatum						

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		July	Aug	Sept	Oct	Nov	Dec
Dinoflagellate	*P. pellucidum*						
	P. pentagonum						
	P. cf *steinii*						
	Protoperidium sp.	○●					
	Pseudonoctiluca kofoidii						
	Pyrocystis lunula						
	Pyrophacus spp.						
	Scrippsiella spinifera						
	S. trochoidea	■●○		○	○●	□○●	□○●
	Spatulodinium pseudonoctiluca						
	cf *Takayama* sp.						
	Warnowia polyphemus						
Diatom	*Amphiprora*			■□○	■□○		□
	Amphora			□●	□●		■
	Asterionellopsis		●	□			
	Bacillaria				○		
	Bellerochia sp.			○	●		
	Chaetoceros sp.			○●	■●		
	Chaetoceros convolutus	■					
	Chaetoceros minimus		●				
	Chaetoceros cf *radians*						
	Chaetoceros tenuissimus						
	Cocconeis sp.			○●	□		
	Coscinodiscus			□○	□○●		□○
	Cyclotella						
	Cylindrotheca closterium		□●	□			
	Cymbella				■		○
	Dactyliosolon		□				
	Ditylum	○●			●		
	Eucampia zodiacus	○●					
	Fragilaria sp.						
	Gyrosigma						
	Lauderia						
	Leptocylindricus minimus				■		
	Licmophora				■		
	Manguinea			□	○		
	Melosira	○●		■□	■	○●	□●
	Navicula			■□○●	■□○●	□	□○
	Nitzschia sp.			□○●	■□○●	□●	■○
	Nitzschia cf *longissima*						□○●
	Paralia sp.			●		○●	○
	Plagiodiscus						
	Plagiotropus			○●	■○		

		July	Aug	Sept	Oct	Nov	Dec
Diatom	*Pleurosigma*			■□○●	■□○●		●
	Pseudo-Nitzschia sp.				○		
	P. pseudodelicatissima						
	Rhizosolenia setigera						
	Rhizosolenia sp.	○●		□	○		
	Skeletonema costatum	□○●	□●	□○●	□●	■○●	■□○●
	Striatella			■			
	Surirella sp.				□		□
	Tabellaria						
	Thalassionema	○●		□○●	■		□
	Thalassiosira eccentrica						
	Thalassiosira pseudonana						
	Thalassiosira sp.			□○●	●		
	Thalassiothrix sp.					■	
Raphidophyte	*Chatonella marina*						
	Fibrocapsa japonica						
	Heterosigma akashiwo						
Prymnesiophyte	*Chrysochromulina* sp.						
	Phaeocystis globosa						
Chlorophyte	Chlorophyte sp.						
	Desmid sp.						
	Ulothrix sp.						○
Heliozoa	*Actinophrys* sp.					●	
Cryptophyte	*Cryptomonas* sp.			■□○	○		
Euglenophyte	*Euglenid* sp.						
Bodonid	sp.			■○●			
Flagellate	small unidentified sp.		□	○●	■●	■□	
Ciliate	*Coleps* sp.			●			
	Eutintinnus sp.						
	Frontonia sp.						
	Mesodinium sp.	○		●		□	□○●
	Paramecium sp.						
	Strombidium sp.						
	Tintinnid sp.	■		○●			
	Trachilocerid sp.						
	Vorticella sp.						
	heterotrich species			●			
	oligotrich sp.						
	unidentified sp.	●		■	■□		○
Macroalgae	*Ulva* sp.						
	Cladophora sp.			□	□		
Pollen	*Pinus* sp.			□○●			□
Ebrid	*Ebria tripartita*			■□	■		
Copepod	nauplii			○	○		
	adult	■					
Rotifer	*Branchionus* sp.					●	
	Synchaeta sp.				●		

		July	Aug	Sept	Oct	Nov	Dec
Ostracod	adult						
Bryozoa	larvae						
Echinodermata	larvae						
Foraminifera							
Polychaete	larvae						■○
Surpulid	larvae	■					
	unidentified larvae						
	shrimp						
	Mysid sp.	■					
	Amphipod sp.			□			
Cnidaria				○●	□○●		
Nematode							
Fish eggs	unidentified sp.						
Egg	unidentified sp.			□			