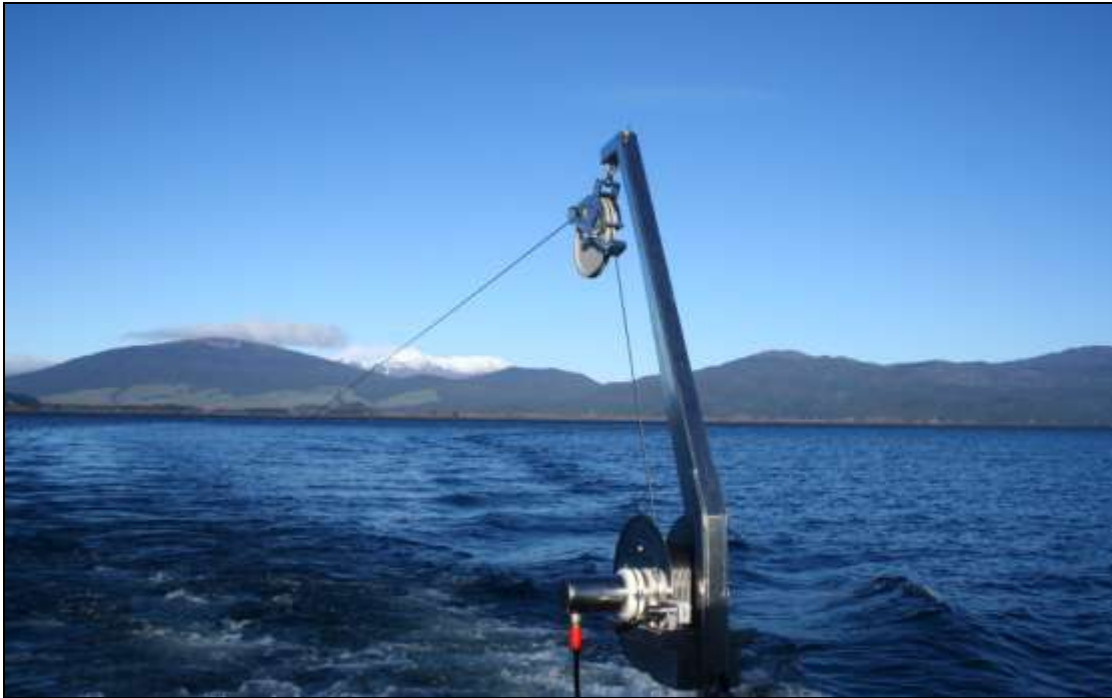


BioFish survey of Lake Taupo, 2006

CBER Report 68

Prepared for Lakes and Waterways Action Group

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30 April 2008



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Introduction

This report provides details of a “BioFish” survey of Lake Taupo conducted in 2006. The first BioFish survey of Lake Taupo was initiated in late 2004 and continued until autumn (May) of 2005 (Hamilton *et al.* 2005). The 2004-5 survey involved deployment of the BioFish along a transect that commenced near the outlet of Lake Taupo, progressed south-west to ‘Station A’, a deep central site near the middle of the lake, and then north-west to include shallower lake bays; Whangamata Bay and Whakaipo Bay. This transect was repeated five times in 2004-5.

One of the objectives of the 2004-5 survey was to examine the time course of horizontal variations in distributions of chlorophyll fluorescence, which is used as a proxy for phytoplankton biomass. A major influence in undertaking the first BioFish survey was the presence of intermittent surface blooms of species of filamentous cyanobacteria (“blue-green algae”) of the genus *Anabaena* early in 2003, through summer and autumn. These blooms arose mostly from aggregations of filamentous *Anabaena circinalis*, though *Anabaena planktonica* was commonly present at lower cell concentrations. Both of these species can be heterocystous, i.e., they may develop anatomical structures (heterocysts) that assist with fixation of free inorganic nitrogen (N₂) from the water column, particularly under conditions of limitation by dissolved inorganic nitrogen (ammonium + nitrate). Many *Anabaena* species observed in oligotrophic lakes of the Central Volcanic Plateau region in summer-autumn have heterocysts.

Anabaena circinalis often constitutes a substantial proportion of measured cell densities in North Island lakes, especially so during late summer in lakes of the Central Volcanic Plateau (Ryan *et al.* 2006). Early in the year of 2003, *Anabaena planktonica* was present at low to moderate densities (< 2,000 cells mL⁻¹) in Lake Taupo but at relatively high densities (occasionally > 15,000 cells mL⁻¹) in some hydro storages of the Waikato River. Both *Anabaena* species can produce toxins and both emit an organic compound, geosmin, which can impart earthy, musty tastes and odours in drinking water. High densities of *Anabaena planktonica* were believed to be mostly responsible for taste and odour problems in drinking water supplied to the city of Hamilton from the Waikato River in 2003.

Several species of cyanobacteria can regulate their buoyancy, including the genera *Microcystis* and *Anabaena*. Buoyancy regulation provides a means of overcoming the vertical separation of light (focused towards the water surface) and nutrients (focused at depth), that often occurs in stratified lakes. Buoyancy is enhanced by aggregations of cells into colonies (e.g. *Microcystis* spp.) or long or coiled filaments (e.g. *Anabaena* spp.). For example, individual cells of the genus *Microcystis*, which are around 5 µm in diameter, can aggregate into colonies often greater than 1 mm in diameter, with corresponding increases in buoyancy of at least 40,000-fold.

Wind blowing over a water surface creates turbulence that tends to negate formation of blooms and entrain cyanobacteria into a deeper mixing layer. By contrast, calm conditions allow buoyancy of cyanobacterial cells to be fully expressed in a phenomenon known as 'telescoping' when there is sufficient time for the cells to rise to the surface. Blooms may be blown onto leeward shores of lakes by light winds that do not disrupt the continuity of the surface bloom (Hamilton, 2001; Robson and Hamilton, 2003). This magnification of cells on the leeward shore may in some cases lead to enormous accumulations or scums of cyanobacteria.

It was with this background that the first BioFish survey of 2004-5 commenced, with an objective of revealing some of the heterogeneity in chlorophyll *a* between near-shore regions and central lake regions that may have been due mostly to cyanobacteria. The first BioFish survey in fact revealed very little heterogeneity in chlorophyll *a* horizontally; reasons for which shall now be discussed. In 2004-5 there were no recorded surface blooms of cyanobacteria in Lake Taupo, and correspondingly low densities of *Anabaena* spp. Furthermore, the BioFish may potentially lack the sensitivity to resolve surface blooms when they occur on scales of millimetres, particularly in the presence of surface quenching (temporary diminishment) of the chlorophyll fluorescence signal which occurs in the presence of bright light (e.g., under typical irradiance levels in clear, surface waters on a sunny day). Lastly, restrictions in accessing very shallow areas by boat while towing the BioFish mean that it is extremely difficult to sample chlorophyll *a* in shallow regions. Despite the problems with capturing surface horizontal heterogeneity of chlorophyll *a* arising from surface blooms in 2004-5, the BioFish survey was extremely useful in revealing the horizontal extent of vertical variations in chlorophyll fluorescence. A pronounced feature of the vertical distribution was the presence of a persistent “deep chlorophyll maximum” (DCM) layer. The DCM varied in depth from 35 to 45 m over the duration of the first four transects and was

absent from the last transect taken in June. Phytoplankton communities that constitute the DCM are generally considered to be tolerant of low temperature, moderate to low light availability and low levels of available phosphorus (Kilham *et al.* 1996; Dokulil and Teubner 2003). Hamilton *et al.* (2005) concluded that the presence of the DCM in Lake Taupo through summer 2004-5 was indicative of a healthy lake phytoplankton community that reflected high water clarity, low levels of nutrients in the surface mixing layer and persistent stratification until winter turnover.

In the 2006 Taupo BioFish survey we introduced a second transect in the south of the lake and also included analysis of phytoplankton species composition. The latter analysis was undertaken to examine variations in species composition between surface populations and populations that constitute the DCM. The southern transect was intended to provide more information about the dynamics of the lake, particularly the role of major inflows in this part of the lake, and the variability of chlorophyll *a* in the shallower waters of the southern basin in proximity to some of the drinking water intakes for small communities in this region.

1. Methods

'BioFish' sampling was conducted on 5 occasions between 1 February and 27 July 2006. Each two-day sampling trip consisted of one day surveying the northern region and a further day surveying the southern region of Lake Taupo. The survey paths on Lake Taupo are shown in Figure 1, along with the six sites at which additional water sampling was conducted. The positions of the six sampling sites are given in Table 1.



Figure 1. Satellite image of Lake Taupo showing the northern and southern BioFish courses. Red circles represent the three water sampling sites for each survey.

Table 1. Details of the six water sampling sites.

Site name	Location (latitude, longitude)		Depth (m)
A	38 46.810S	175 58.440E	176
Whangamata Bay	38 39.936S	175 55.125E	26.5
Whakaipo Bay	38 41.223S	175 57.598E	36
S1	38 50.798S	175 48.968E	101
S2	38 56.289S	175 45.605E	71
S3	38 54.251S	175 54.655E	51

The BioFish is a towed, undulating instrument designed to collect real-time, high frequency water quality data using a suite of fast-response sensors (Figure 2).

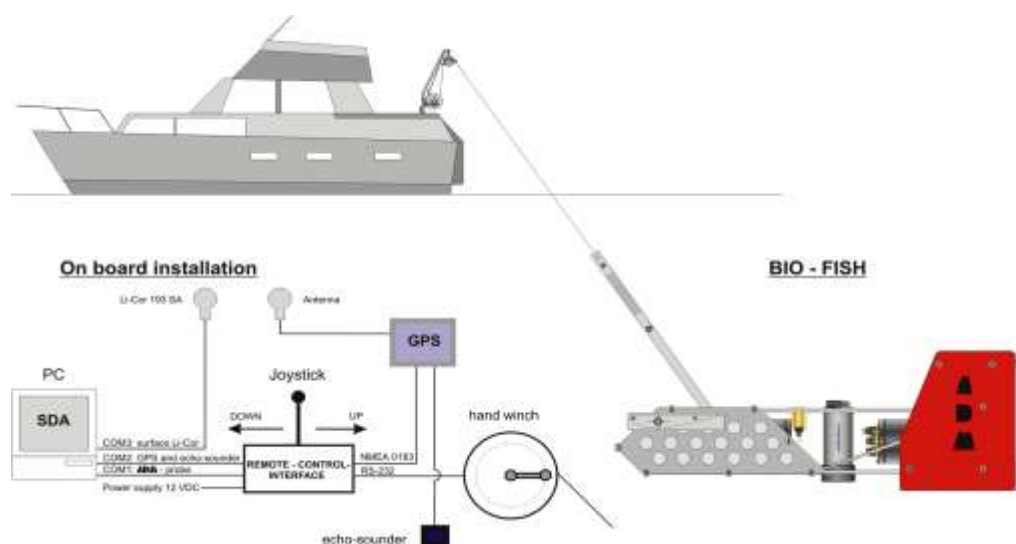


Figure 2. Boat and on-board and underwater set up of BioFish. Note: not to scale (BioFish probe is approximately 0.8 m in length).

The system consists of a multi-sensor probe, steering motor, winch, power supply, software interface and computer. The depth of the BioFish probe is positioned with ‘wings’ and can also be adjusted by altering boat speed. The BioFish probe is equipped with 7 sensors which measure water depth, temperature, conductivity, dissolved oxygen, chlorophyll fluorescence, light transmittance and incoming (planar) photosynthetically active radiation (PAR) at 4 Hz; details of these sensors are provided in Table 2. Data are recorded in real-time on a computer together with Global Positioning System longitudinal and latitudinal positions and depth from an echo sounding.

Table 2. BioFish sensor details.

Probe	Manufacturer	Resolution	Accuracy	Response time
Pressure	Keller	0.01 dBar	± 0.1 % FS	20 ms
Temperature	ADM-Elektronik	0.001 °C	± 0.01 °C	20 ms
Conductivity	ADM-Elektronik	0.001 mS cm ⁻¹	± 0.01 mS cm ⁻¹	50 ms
Dissolved oxygen	AMT Analysenmeßtechnik GmbH	0.1 % saturation	1.5 % of saturation	c. 200 ms
Transmissiometer	ADM-Elektronik	0.01 %	1 %	50 ms
Fluorometer	Dr. Haardt Optik Mikroelektronik miniBackScat	0.05 µg L ⁻¹	Not quantified	150 ms
Photosynthetically active radiation (PAR)	Li-Cor 192 SA	Not quantified	± 5 % reading	Not quantified

BioFish data stored on a field computer were processed using Ocean Data View software in order to generate colour ‘curtains’ of the data obtained from the temperature, dissolved oxygen, conductivity, transmissiometer and fluorometer sensors on the probe. The curtain scale dimensions are presented as distance from commencement of each transect (e.g., horizontal axis starting adjacent to the Harbour Master’s Office for the northern transect) and depth (vertical axis).

Readings from the BioFish were validated in a number of ways. Conductivity-temperature-depth profiles that also included beam transmittance, fluorescence and photosynthetically active radiation (PAR), were taken with a Sea-Bird ‘CTD’ (referred to hereafter as CTD profiles) at three sites during the BioFish runs. These data were used to ‘calibrate’ the temperature, dissolved oxygen, fluorometer and conductivity probes on the BioFish. The use of the CTD in this mode was considered to provide a good cross-check on the validity of the BioFish readings.

In order to quantify horizontal and vertical differences in water temperature, dissolved oxygen and chlorophyll fluorescence, further statistical analyses were undertaken for two northern transects 16-03-06 and 19-04-06). Three shallow bays and a region of the deep lake were selected for comparison, and two separate analyses were conducted. The first grouped data by the depth of the lake bed, and the second by sample depth. The deep lake was considered to be those data from a water depth of greater than 50 m, whereas the shallow bays were defined as a water depth

of less than 50 m from within set geographical ranges. The sites and selection criteria are given in Table 3.

Table 3. Details of sample sites used for the statistical analysis of two BioFish transects. (n/a = not applicable.)

Site	Location: BioFish data	BioFish sample numbers	Minimum lake bed depth range
Taupo bay	N of 38° 43.690S	Mar: 1 - 698 Apr: 1 - 649	0 - 20 m
Whangamata Bay	N of 38° 40.177S	Mar: 4741 - 4883 Apr: 4527 - 4806	0 – 30 m
Whakaipo Bay	E of 175° 57.162E	Mar: 6428 - 6680 Apr: 6491 - 6675	0 – 20 m
Deep lake	Between Taupo and Whangamata Bays	Mar: 699 - 4740 Apr: 650 - 4526	n/a

2. Results

BioFish and CTD profiles

Nine BioFish transects were completed between 1 February and 24 July 2006, four for the northern path and five for the southern path shown in Figure 1. On 1 February, an electrical malfunction prevented use of the BioFish. Figures 3 through 10 show water temperature, dissolved oxygen, specific conductance and chlorophyll fluorescence data from the BioFish transects, using colour contour plots. CTD data are presented where technical difficulties prevented collection of BioFish data.

Over the study period, Lake Taupo progressed from strongly stratified on 1 February with temperatures from around 22°C in surface waters to roughly 10°C in the hypolimnion, to fully mixed on 24 July when water temperature was fairly homogeneous throughout the lake at approximately 10°C. Mixing occurs when lake surface-waters cool to an extent that they sink and ultimately become entrained throughout the water column.

Figures 3 and 4 show the sequence of five transects of temperature taken in the northern and southern parts of the lake, respectively, between 1 February and 24 July 2006. The first four northern and southern BioFish profiles show the thermocline (the depth with the most rapid rate of temperature change with depth) which deepens from around 35 m on 1 February to more than 60 m by 31 May 2006. There was some evidence of horizontal variations in water temperature (warming) between the deep open water and shallower bays, particularly during the warmer months.

Figures 5 and 6 show the sequence of dissolved oxygen recordings taken in the northern and southern parts of the lake, respectively, between 1 February and 24 July 2006. The first transect on 1 February includes only CTD casts as the BioFish malfunctioned. The stratification in summer is clear with some variation of readings of dissolved oxygen at different depths. As the lake becomes cooler in winter and turns over, the mixing results in even oxygen levels throughout the water column. A mid-depth area of rapid change of dissolved oxygen corresponds to the thermocline. Note also the gradual depletion of levels at greater depths by 24 April before the

surface waters cool with a subsequent rise in levels at mid-depth by 31 May, before the turnover in winter. In Figure 6(B) lower oxygen levels than surrounding depths are revealed as a green band; this corresponds to a mid-depth (metalimnion) minimum of dissolved oxygen.

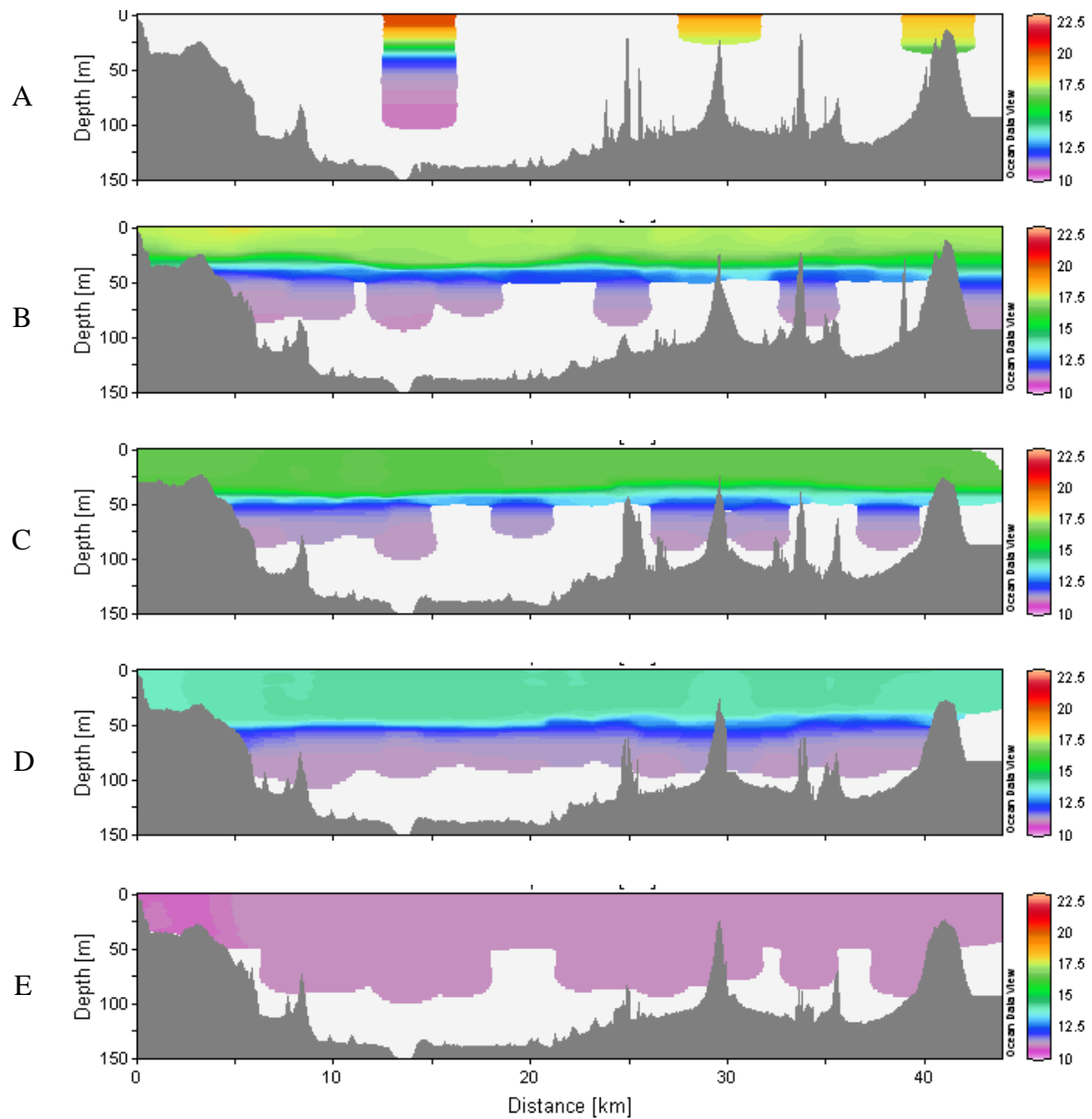


Figure 3. Temperature ($^{\circ}\text{C}$) in Lake Taupo from BioFish runs of the northern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06. The BioFish was not operational on 01-02-06; therefore, vertical CTD profiles at each of the 3 water sampling sites are presented for this date.

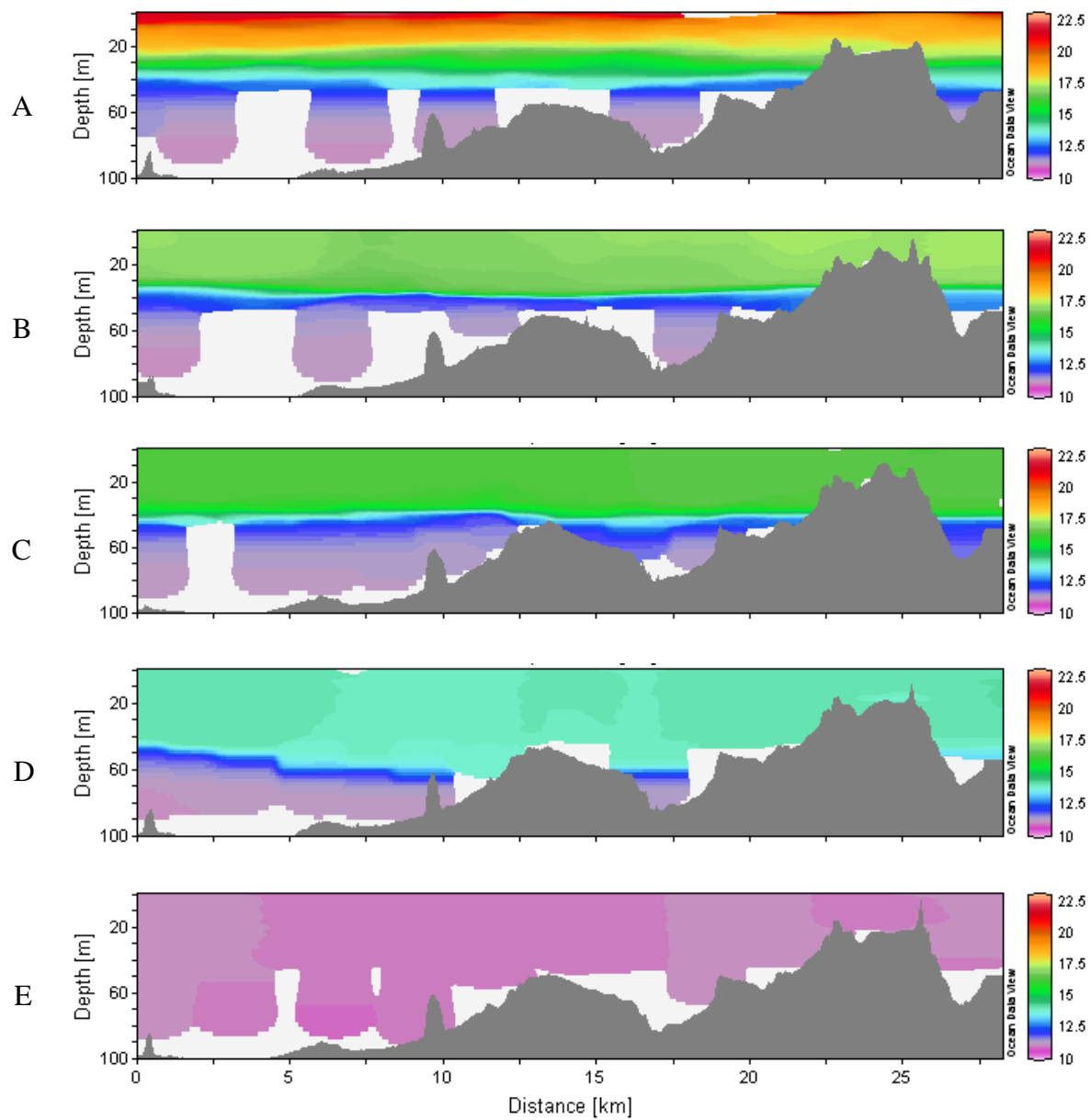


Figure 4. Temperature ($^{\circ}\text{C}$) in Lake Taupo from BioFish runs of the southern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06.

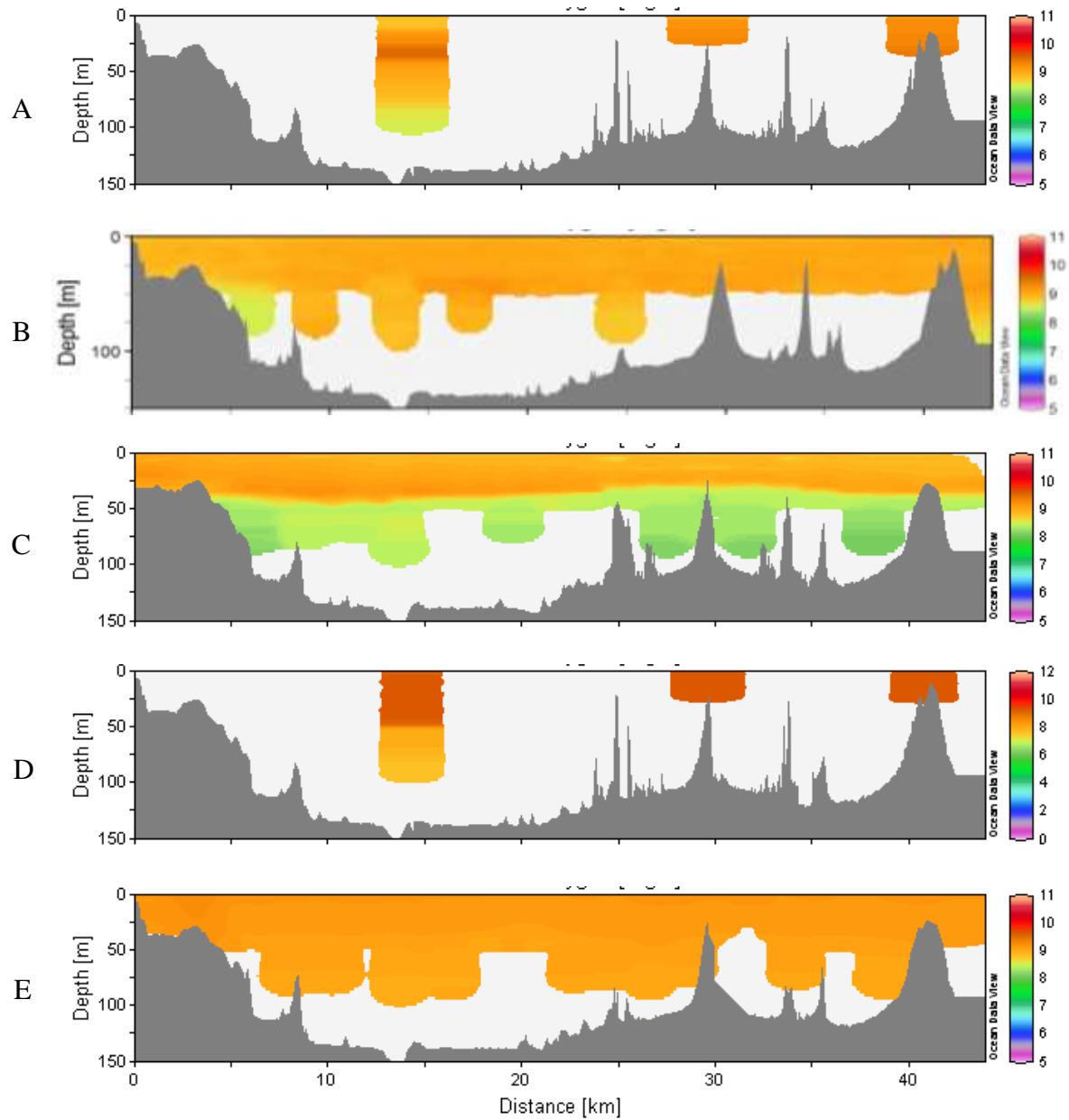


Figure 5. Dissolved oxygen (mg L^{-1}) in Lake Taupo from BioFish runs of the northern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06. The BioFish was not operational on 01-02-06; therefore, vertical CTD profiles at each of the 3 water sampling sites are presented for this date. Plot D (31-05-06) represents vertical CTD cast data only, due to expiration of the BioFish oxygen sensor membrane.

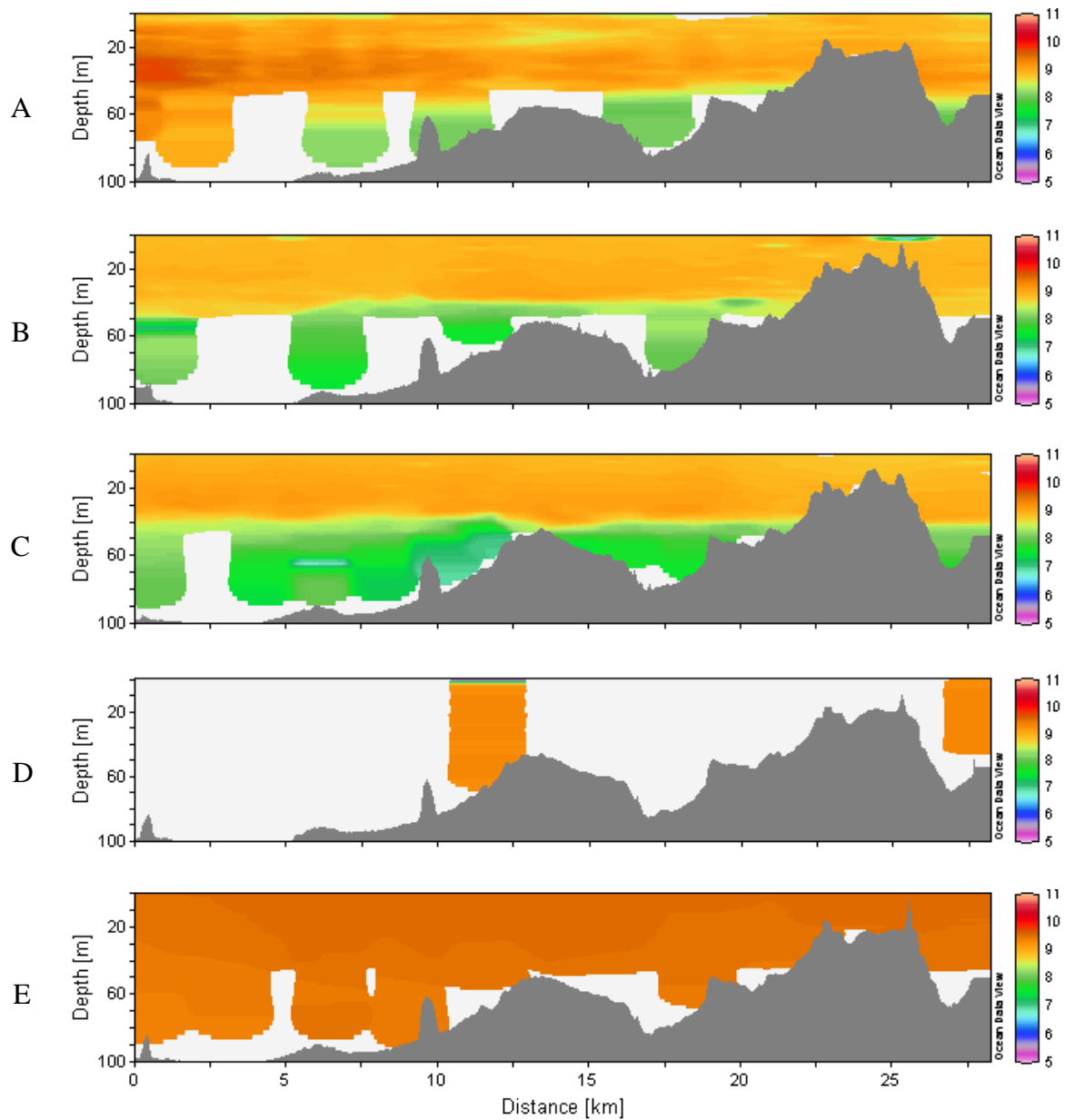


Figure 6. Dissolved oxygen (mg L^{-1}) in Lake Taupo from BioFish runs of the southern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06. Plot D (31-05-06) represents vertical CTD cast data only, due to expiration of the BioFish oxygen sensor membrane.

Figure 7 shows the sequence of specific conductance readings (corresponding approximately to salinity) taken in the northern part of the lake (northern transect) between 1 February and 24 July 2006. The first transect on 1 February includes only CTD casts as the BioFish malfunctioned. The conductivity at the surface is generally lower when the lake is strongly stratified and then

increases just prior to winter turnover as bottom waters start to become entrained in surface waters. An area of interest is around 14 km distance into the transect (horizontal scale) where conductivity is raised compared with the adjacent horizontal waters. The source of this water is not obvious but it is unlikely to be from the Tongariro River inflow, which has a mostly lower salinity than the lake, nor from the Tokaanu Tailrace, which has a salinity comparable to the lake (Spigel *et al.* 2005), but it could be of geothermal origin. The northern lake where the transect starts (see Figure 1) also has higher levels of conductivity, likely reflecting some localised tributary inputs with higher conductivity including local geothermal sources in this part of the lake.

Chlorophyll levels in Lake Taupo from BioFish fluorescence transects are shown in Figure 9, for the northern part of the lake on the five dates. The BioFish was not operational on 1 February 2006, and therefore CTD profiles at each of the three water sampling sites are presented for this date. Fluorescence values generally increased from the beginning to the end of the study period, in keeping with the results of solvent-extracted chlorophyll analyses presented in Figure 13.

The fluorescence transects revealed some interesting horizontal and vertical variations in chlorophyll *a*, including presence of a deep chlorophyll maximum (DCM) on several occasions. In the northern lake, a strong DCM was present at around 50 m on 1 February and appeared to persist until at least late April. The deep chlorophyll maximum (DCM) was only really evident on April 20 as a higher level of chlorophyll fluorescence at a depth of nearly 50 m (Figure 9C). Despite winter mixing, on 24 July the open water around Site A continued to have lower fluorescence levels than near-shore regions. Although chlorophyll is relatively evenly distributed in the lake on 24 July, the waters from 10-20 km along the northern transect appear to be generally lower (Figure 1). The DCM was less well defined in the southern transect (Figure 10). Both northern and southern transects demonstrated very clearly the large increase in fluorescence when the water column was well mixed, on the last day sampling day. The increase in chlorophyll at this time was greater in the southern transect, while there were distinctly lower levels between 10 and 20 km in the northern transect, as mentioned above.

Chlorophyll fluorescence levels can be suppressed by saturating levels of solar irradiance (solar “quenching”). This effect can be seen in several of the BioFish transects, which commenced at

around 5am (in the absence of sunlight), finishing around midday. On relatively cloud-free days, increasing irradiance towards solar noon results in reduced fluorescence in exposed surface waters. This effect can be observed in the transects as a surface band of low fluorescence, increasing in depth towards the end of the transect (Figures 9B, 9D, 9E, 10B, 10C, 10D and 10E).

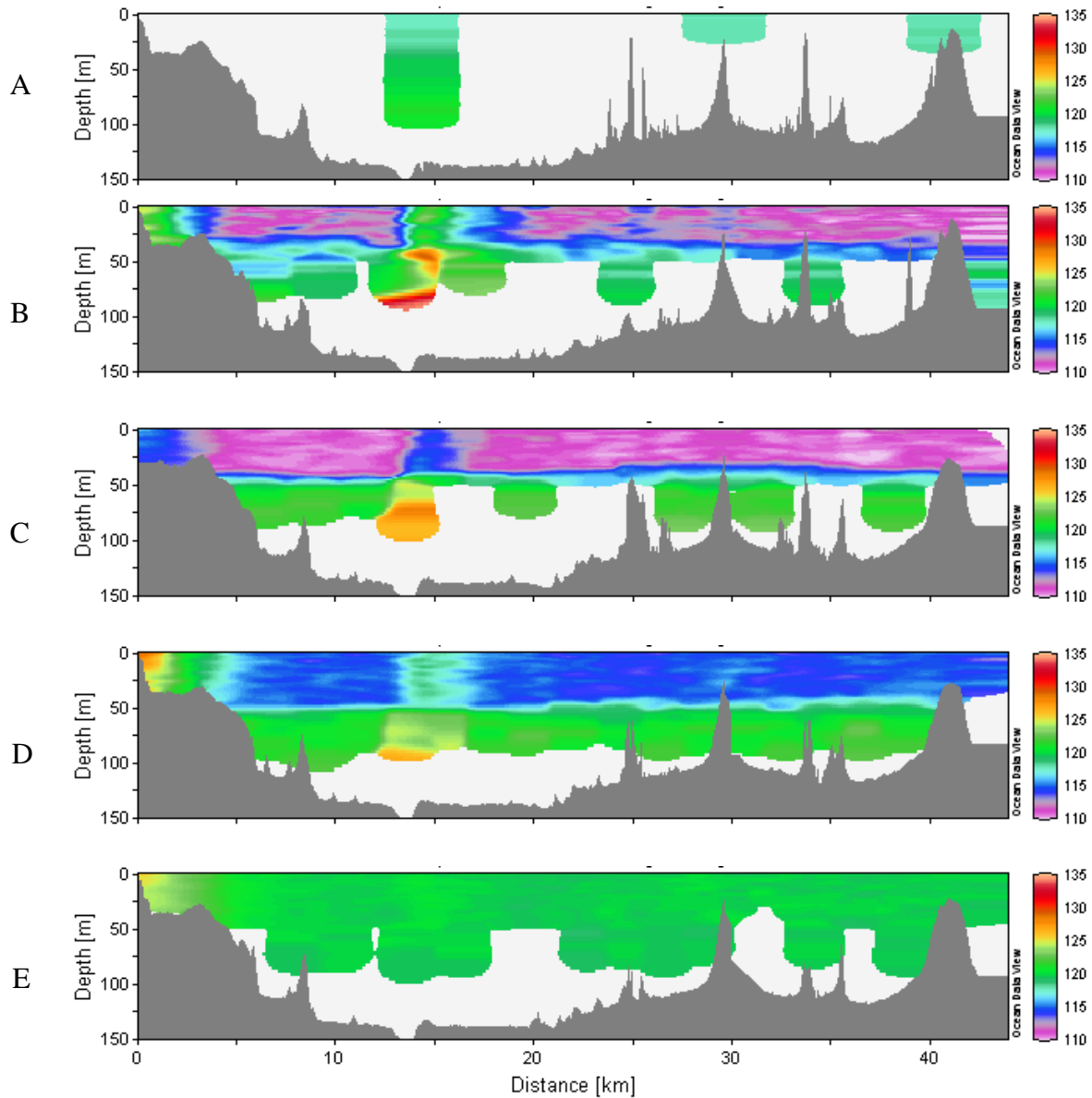


Figure 7. Specific conductance ($\mu\text{S cm}^{-1}$) in Lake Taupo from BioFish runs of the northern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06. The BioFish was not operational on 01-02-06; therefore, vertical CTD profiles at each of the 3 water sampling sites are presented for this date.

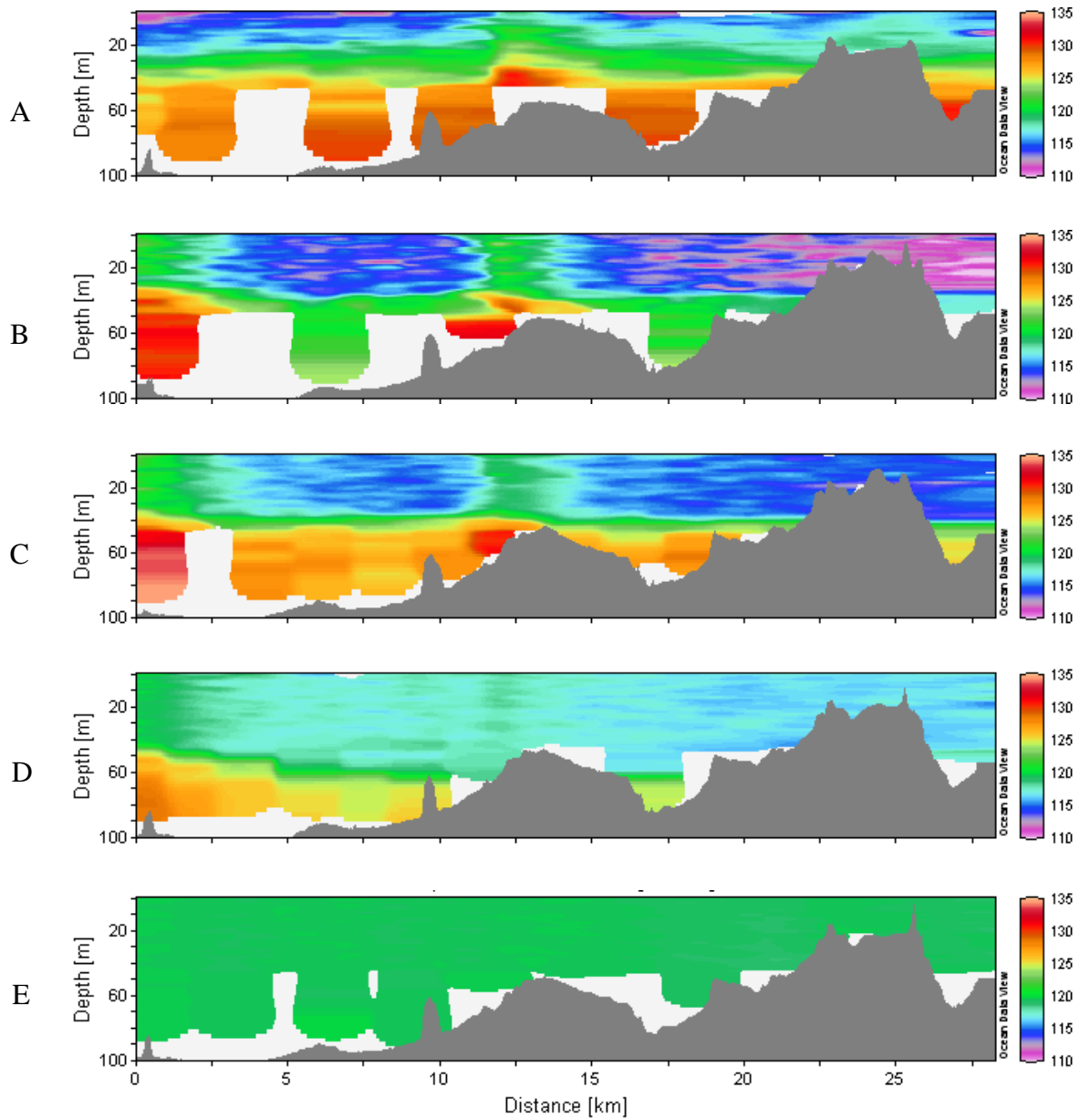


Figure 8 Specific conductance ($\mu\text{S cm}^{-1}$) in Lake Taupo from BioFish runs of the southern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06.

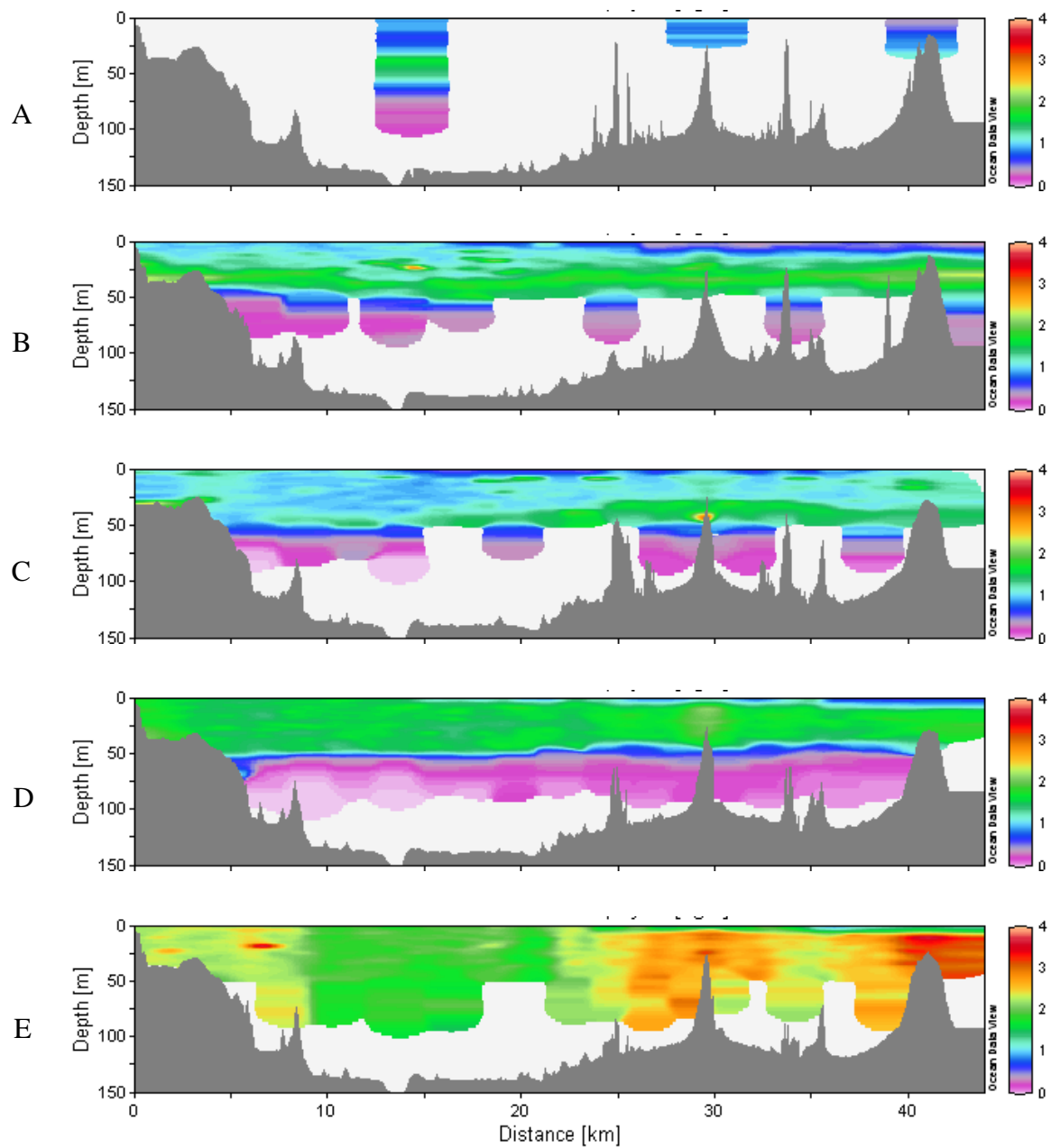


Figure 9. Chlorophyll fluorescence (approximating to $\mu\text{g L}^{-1}$) in Lake Taupo from BioFish runs of the northern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06. The BioFish was not operational on 01-02-06; therefore, vertical CTD profiles at each of the 3 water sampling sites are presented for this date.

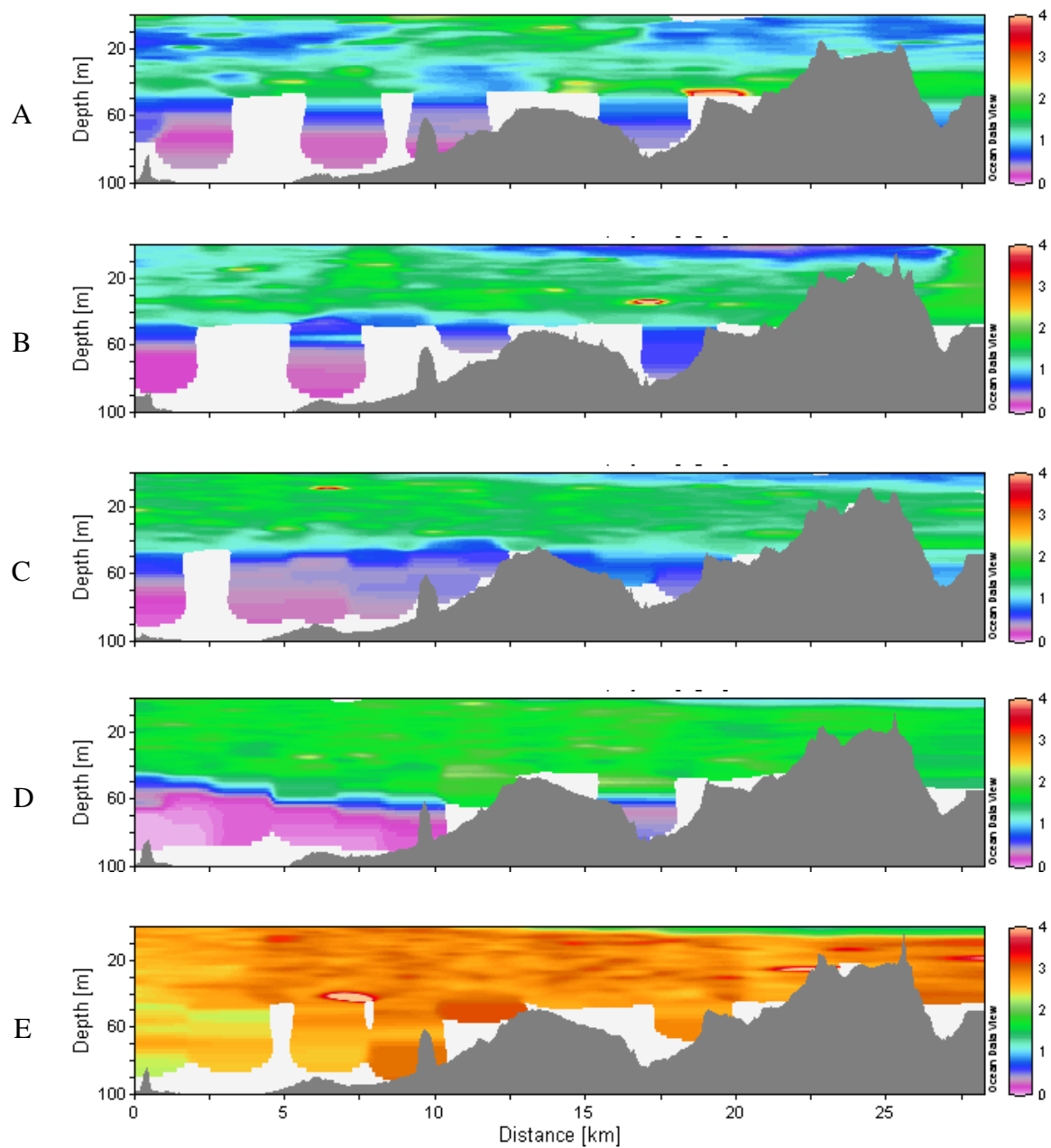


Figure 10. Chlorophyll fluorescence (approximating to $\mu\text{g L}^{-1}$) in Lake Taupo from BioFish runs of the southern transect on the five dates. A) 01-02-06, B) 15-03-06, C) 20-04-06, D) 31-05-06 and E) 24-07-06.

Figure 11 illustrates CTD profiles collected from Site A on five days in 2006, and includes A) temperature, B) dissolved oxygen, C) chlorophyll fluorescence and D) specific conductance. Temperature shows a well developed seasonal deepening of the surface mixed layer. This layer is differentiated as the region from the water surface to where the temperature is no longer homogeneous. The depth of the surface mixed layer varies from < 10 m on 2 February to nearly 50 m by 1 June, with surface water temperature varying from > 20 °C to approximately 14 °C for these two respective dates. By 27 July the water column temperature is almost homogeneous at around 11 °C, also corresponding to the temperature of the hypolimnion (bottom waters) during the stratified period. Concentrations of dissolved oxygen show less relative variation than for temperature, and only the last stratified transect on 1 June shows clearly a lower concentration in bottom waters, but only by about 1 mg L⁻¹. Chlorophyll fluorescence shows a marked seasonality. Over the stratified period fluorescence is reasonably constant in bottom waters. There is some evidence of solar quenching, denoted by strongly reduced fluorescence near the water surface, presumably as a result of high light levels on 1 June, but little evidence of this phenomenon for the other transects. The depth of the fluorescence maximum is reasonably consistent at around 40 to 45 m in all of the stratified samples except for 1 June when the fluorescence maximum had broken up and fluorescence in the surface mixed layer had increased markedly compared with the earlier transects taken when the water column was stratified. Specific conductance provides a good marker for temperature stratification and water column mixing. A major change in conductance occurs following turnover in the 27 July transect, when it becomes far higher in the surface mixed layer and decreases in the hypolimnion compared with 1 June. The other notable change is the greater depth of lower conductance water on 1 June corresponding to a greater depth of the surface mixed layer. All of these results are consistent with what has been established previously for Lake Taupo, with a period of low phytoplankton biomass in summer, a period of rapidly increasing biomass prior to winter turnover, and maximum biomass in winter when the water column is essentially fully mixed.

Site S2 recordings in Figure 12 show the summer stratification and winter mixing (green line) and some solar quenching in the pink trace in fluorescence. The salinity levels recorded by specific conductance show a spike in levels at 35-40m depth reaching almost 130 $\mu\text{s cm}^{-1}$ on 15 March. By 31 May, the tracing is linear (pink line) which is earlier mixing than at site S1 which still shows stratification on June 1 (Figure 11D).

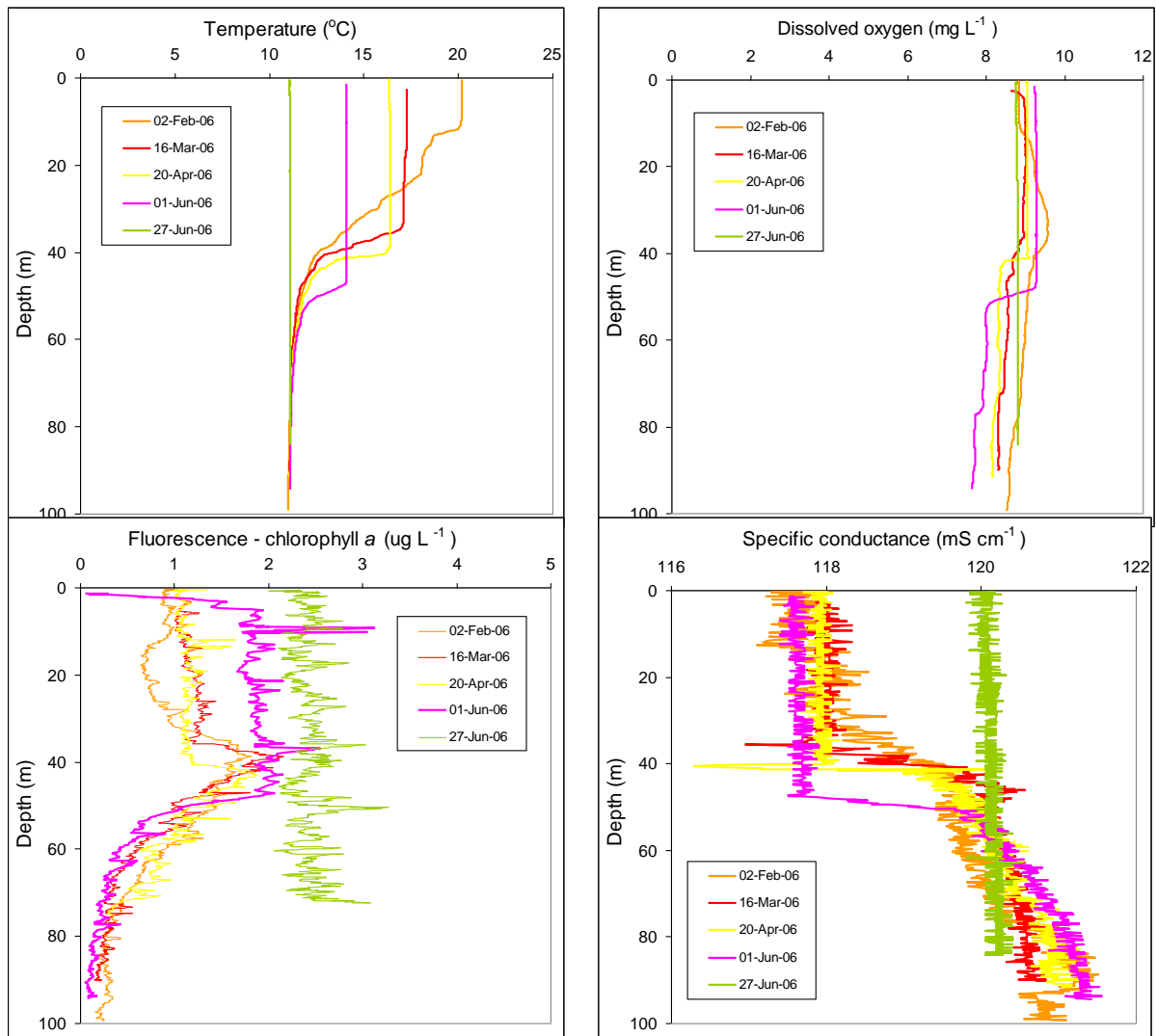


Figure 11. CTD profiles collected from Site A of A) temperature, B) dissolved oxygen, C) fluorescence and D) specific conductance on 5 days in 2006 (NB: specific conductance is measured in $\mu\text{mS cm}^{-1}$).

Temperature and oxygen profiles at site S2 (Figure 12) show similar patterns, although turnover appears to occur earlier, with the thermocline being barely distinguishable on 21 May. Minimum oxygen levels in the hypolimnion during stratification are slightly lower than at site A. Deep fluorescence maxima are also less pronounced than at site A, but do possibly occur on 16 March and 20 April. Dramatic spikes in conductivity can be seen on 3 occasions, probably due to intrusion of the Tongariro River near the delta as it inserts at its level of neutral buoyancy, determined mostly by its temperature relative to the water column temperature.

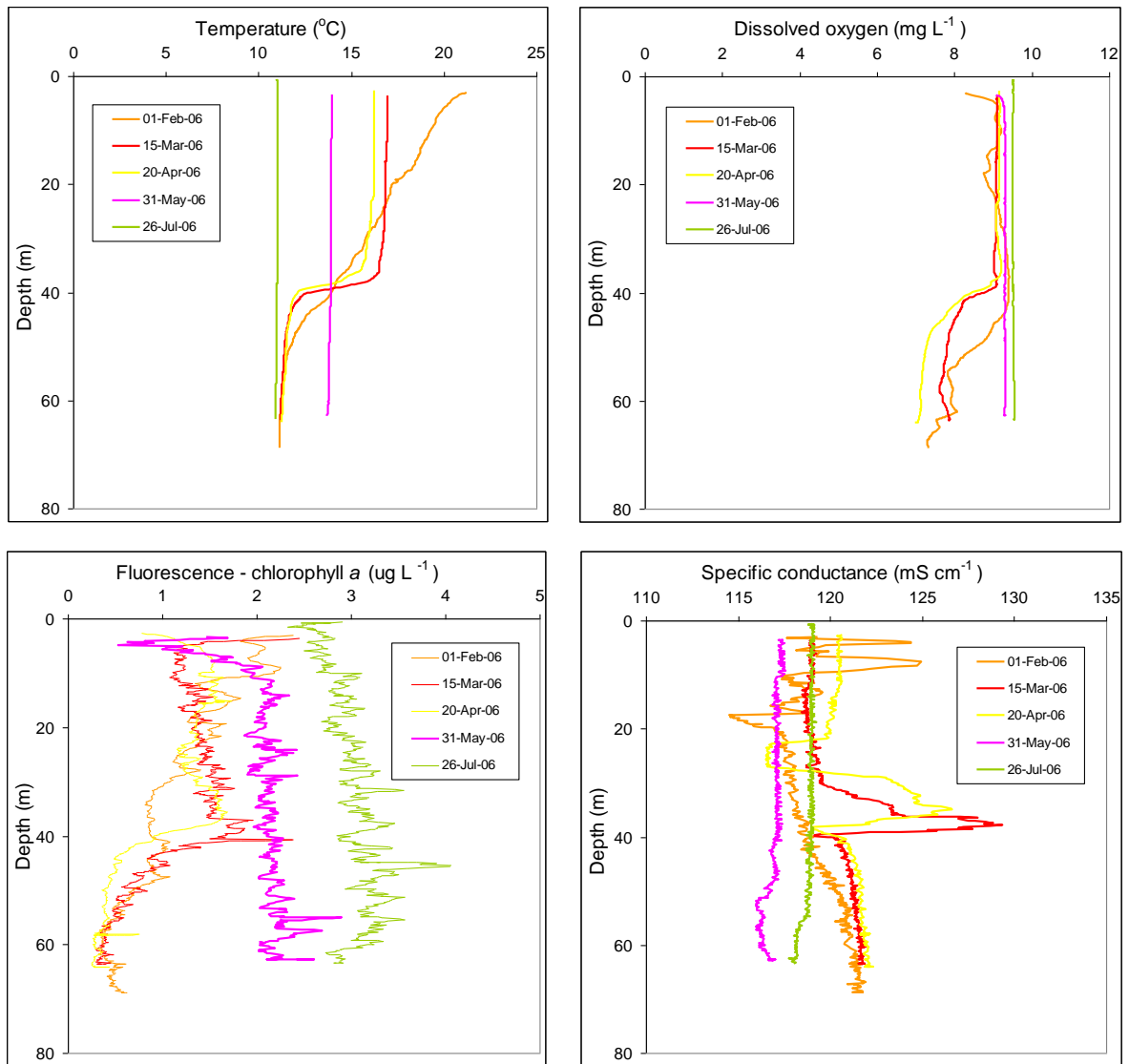


Figure 12. CTD profiles collected from Site S2 of A) temperature, B) dissolved oxygen, C) fluorescence and D) specific conductance (NB: specific conductance is measured in $\mu\text{mS cm}^{-1}$)

Chlorophyll a analysis and phytoplankton cell counts

Solvent extracted chlorophyll *a* from water samples from 0 and 15 m (Figure 13) show a trend of increasing concentration at all sites over the study period. Exceptions to this are Whakaipo Bay and site S2, which had elevated levels of chlorophyll on 1 February. Chlorophyll levels at 0 and 15 m were generally very similar.

Surface phytoplankton communities generally followed a similar pattern of species succession (Figures 14 to 19). Warmer months (February to May) were characterised by a strong presence of cyanobacteria, and also diatoms in the case of the southern sites. Dominant cyanobacteria species were *Aphanizomenon gracile* and *Anabaena* spp. Between March and June, green algae were generally dominant, comprising >80% of all cells on at least one occasion for all sites. This dominance was usually due to an abundance of *Monoraphidium* sp., although *Botryococcus* and *Oocystis* species were also often prevalent. By July, most sites showed evidence of the usual dominance of diatoms during winter. Diatom species at this time varied between sites, and included *Fragillaria crotonensis*, *Aulocoseira granulata*, and *Asterionella formosa*. Chrysophyte species were usually present at all sites, but usually in low abundance. No consistent trends were observed in total cell counts. This inconsistency with levels of chlorophyll *a* most likely reflects variations in size of cells of each species so that they have different levels of chlorophyll *a* per cell. Peak cell counts were in February for site S2, March for site S1 and Whakaipo Bay, and June for Sites A, S3 and Whangamata Bay.

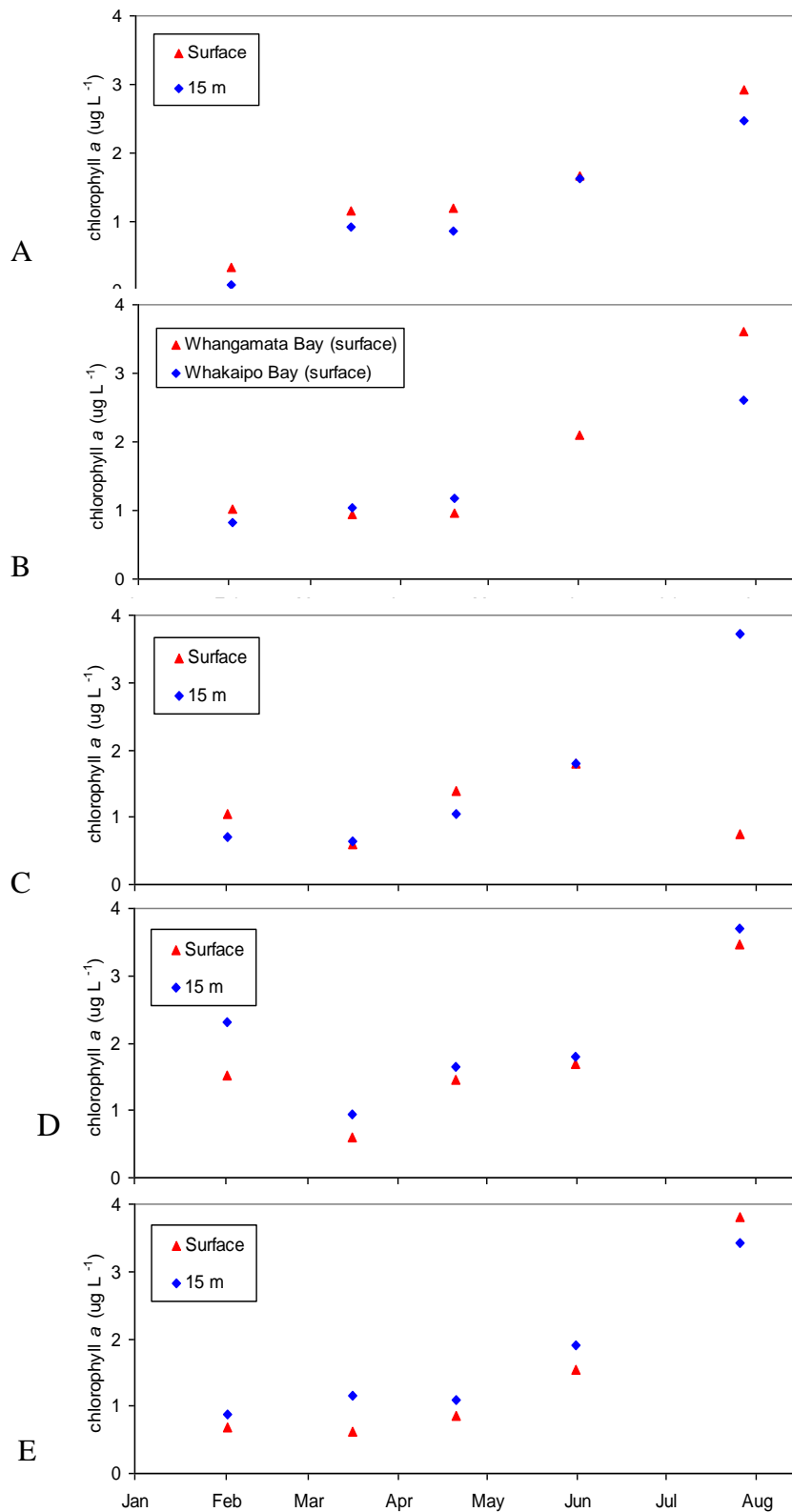


Figure 13. Chlorophyll a concentrations for A) site A, B) Whangamata and Whakaipo Bays, C) site S1, D) site S2 and E) site S3.

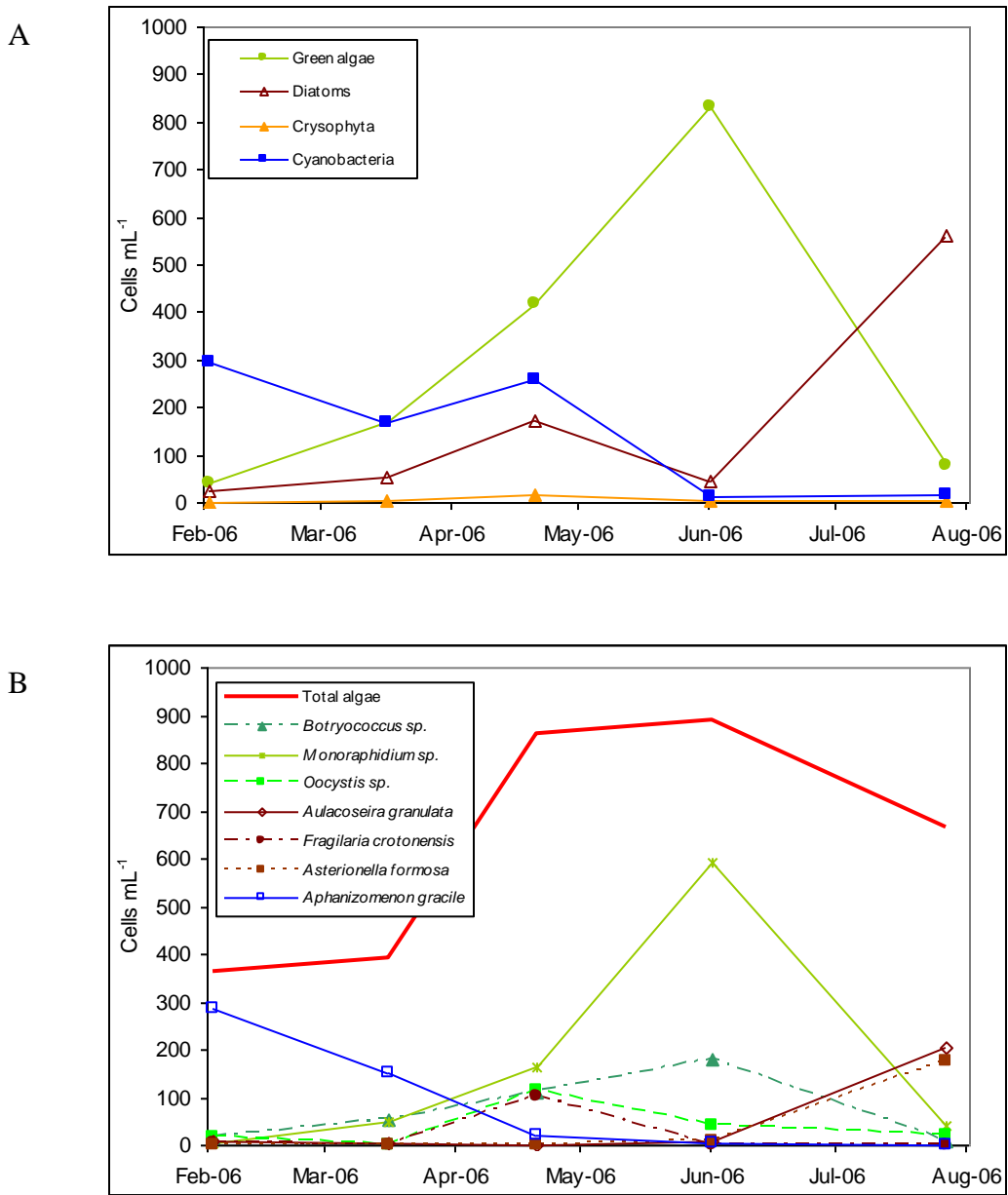


Figure 14. Phytoplankton cell counts for Site A. A) Total cell counts for the 4 main algal groups observed. B) Total counts for all taxa, and counts for any species exceeding 100 cells mL⁻¹ on at least one occasion.

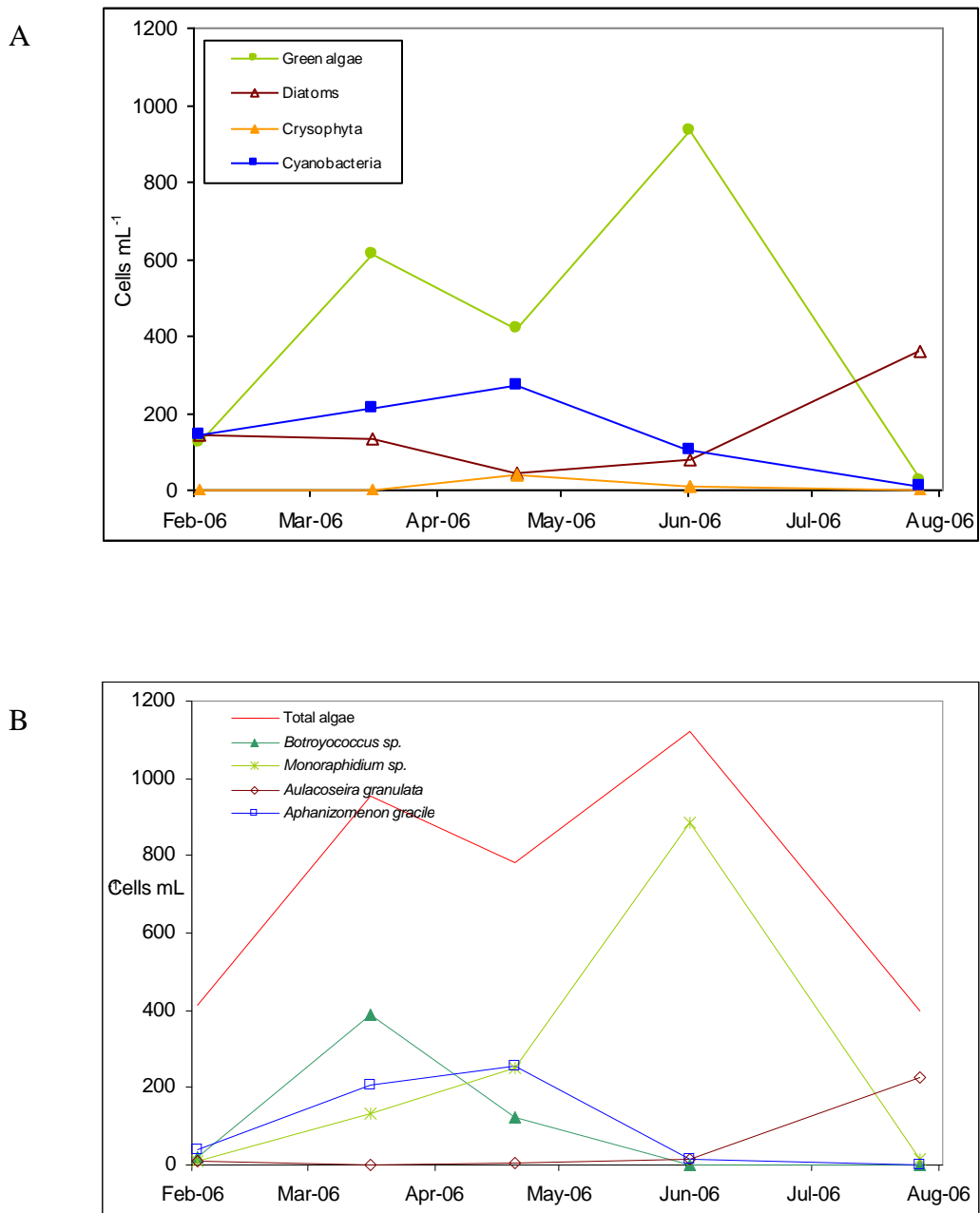


Figure 15. Phytoplankton cell counts for Whangamata Bay. A) Total cell counts for the 4 main algal groups observed. B) Total count for all taxa, and counts for any species exceeding 100 cells mL⁻¹ on at least one occasion.

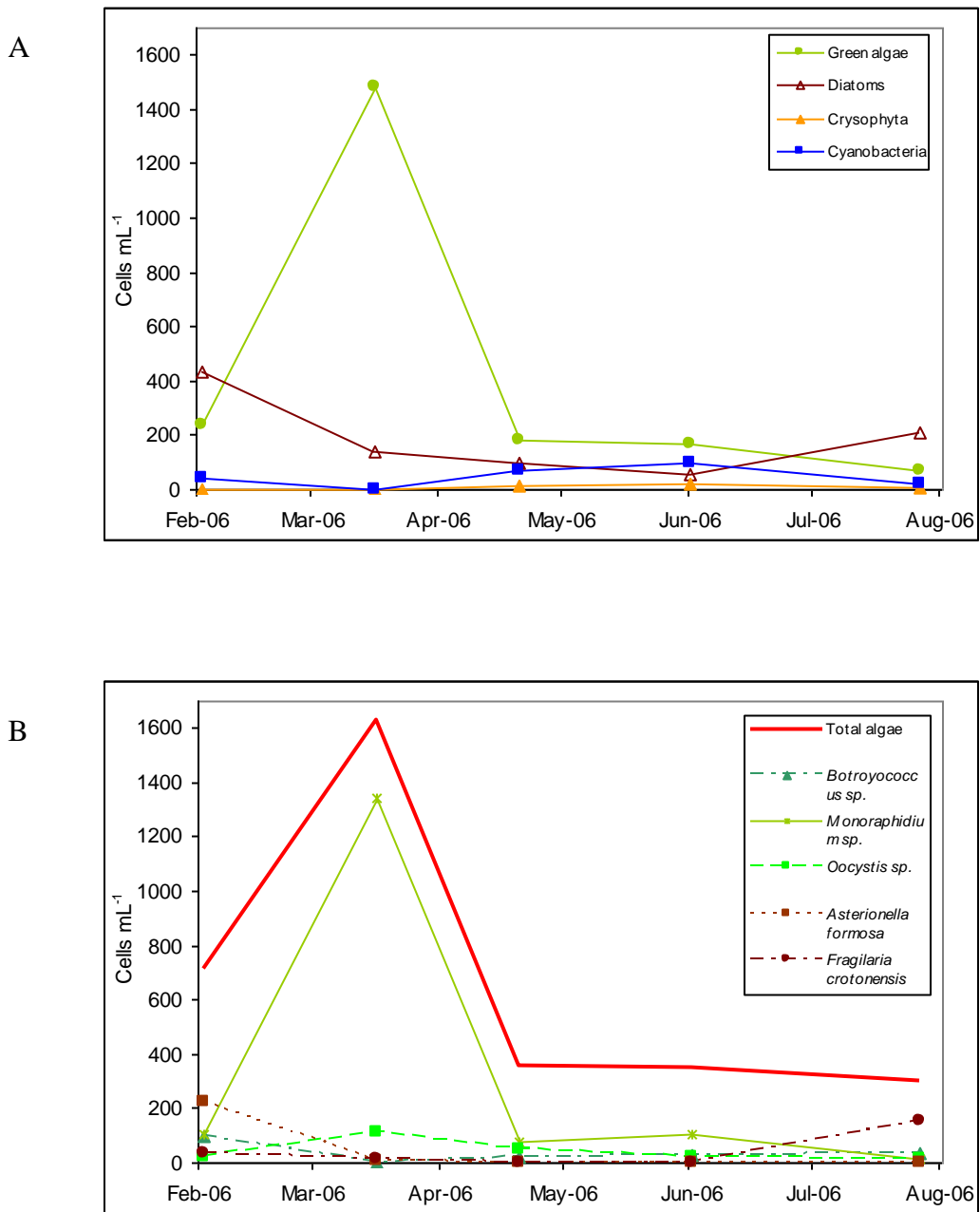


Figure 16. Phytoplankton cell counts for Whakaipo Bay. A) Total cell counts for the 4 main algal groups observed. B) Total counts for all taxa, and counts for any species exceeding 100 cells mL⁻¹ on at least one occasion.

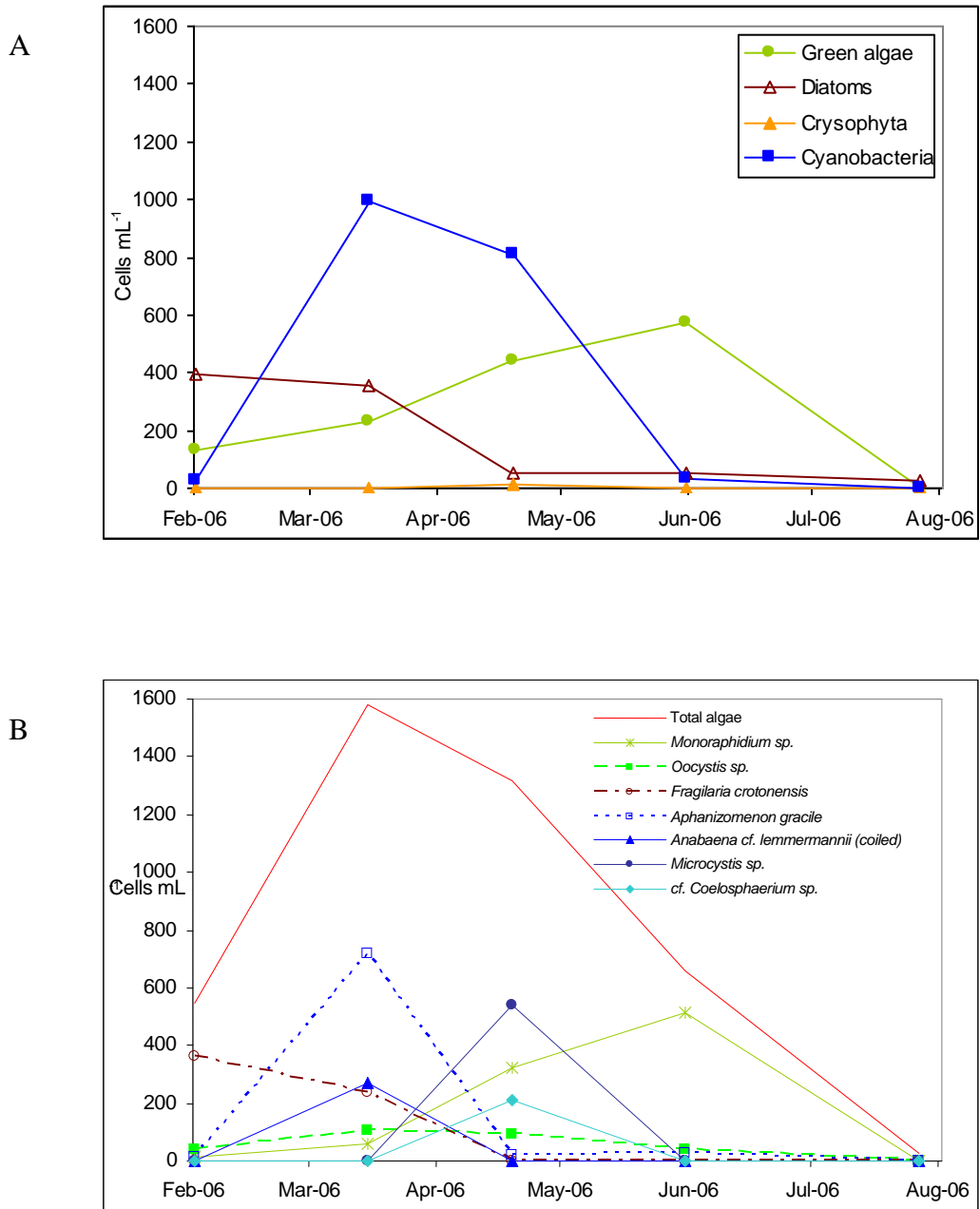


Figure 17. Phytoplankton cell counts for site S1. A) Total cell counts for the 4 main algal groups observed. B) Total counts for all taxa, and counts for any species exceeding 100 cells mL⁻¹ on at least one occasion

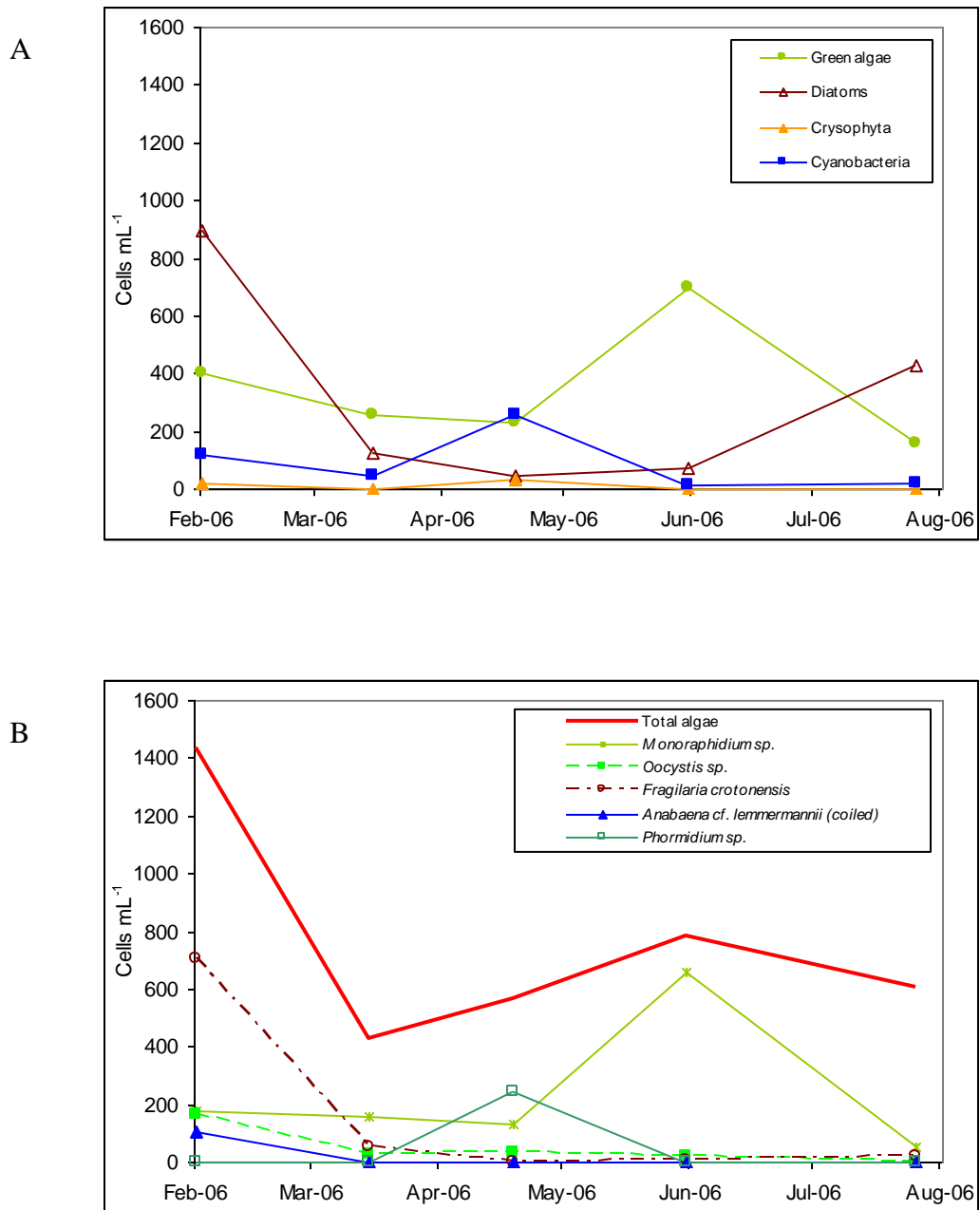


Figure 18. Phytoplankton cell counts for site S2. A) Total cell counts for the 4 main algal groups observed. B) Total counts for all taxa, and counts for any species exceeding 100 cells mL⁻¹ on at least one occasion.

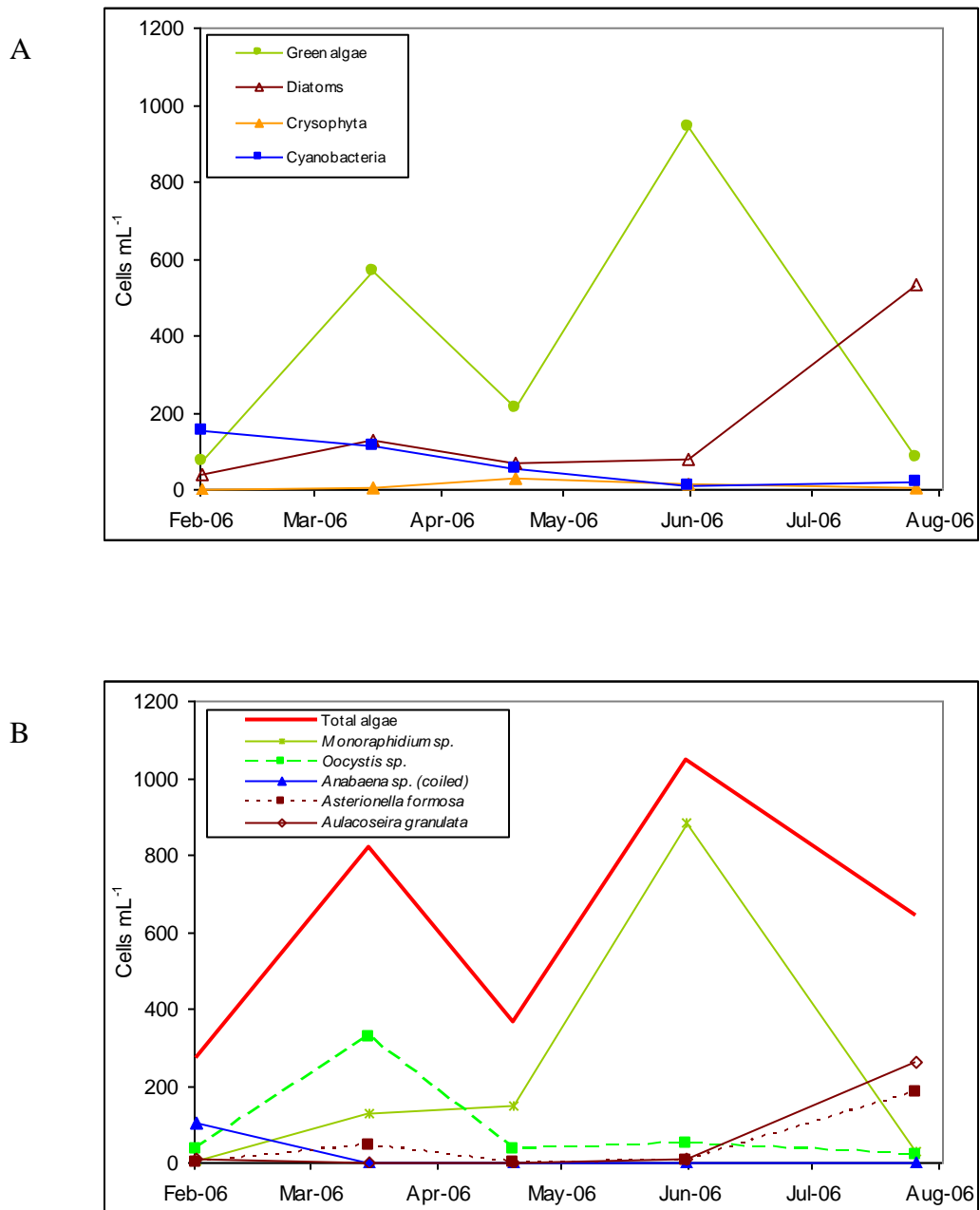


Figure 19. Phytoplankton cell counts for site S3. A) Total cell counts for the 4 main algal groups observed. B) Total counts for all taxa, and counts for any species exceeding 100 cells mL⁻¹ on at least one occasion.

Spatial analyses

Aggregation of temperature, dissolved oxygen and chlorophyll fluorescence data from the northern transect by bottom depth (Figures 20 and 21) revealed some interesting spatial variations in water quality. For the March transect (Figure 20), consistent variations in water temperature were observed, with Taupo Bay being the warmest followed by Whangamata and Whakaipo Bays, and the deep lake (aggregated by sample depth not bottom depth) being the coldest. The range of median temperatures was, however, relatively small (<0.5 °C). As expected with the influence of surface heating in summer, shallower sites in each bay were generally warmer than deeper areas during the daytime period of the BioFish transects, though not in Taupo Bay. However, by April (Figure 21) the temperature differences between the bays were less pronounced.

Very little variation in dissolved oxygen was observed either within or between sites. Some striking differences in chlorophyll fluorescence between bays and the deep lake can be seen in Figure 20 (March), with Taupo Bay and the deep lake having much higher fluorescence values than Whangamata and Whakaipo bays. There is also a general trend of increasing fluorescence with bottom depth. In April (Figure 21) differences in fluorescence were less pronounced, and the reverse situation was observed, whereby Whangamata and Whakaipo Bays had higher fluorescence than Taupo Bay and the deep site.

Aggregating data by sample depth showed some strong vertical variations at each site. This is to be expected, given the water column profiles observed in Figures 11 and 12. Comparisons of temperature between sites at similar sample depths suggests that in March (Figure 22) the thermal profile of the water column was quite different between the four regions. In April, the deepening thermocline and reduced solar heating resulted in much smaller differences between depths and sites. Again, little variation in dissolved oxygen was found, although Taupo Bay appeared to be slightly less oxygenated than other regions. Variations in chlorophyll fluorescence were again more pronounced in March than April. Interestingly, in March vertical variations in chlorophyll were generally lower than variations between different horizontal areas.

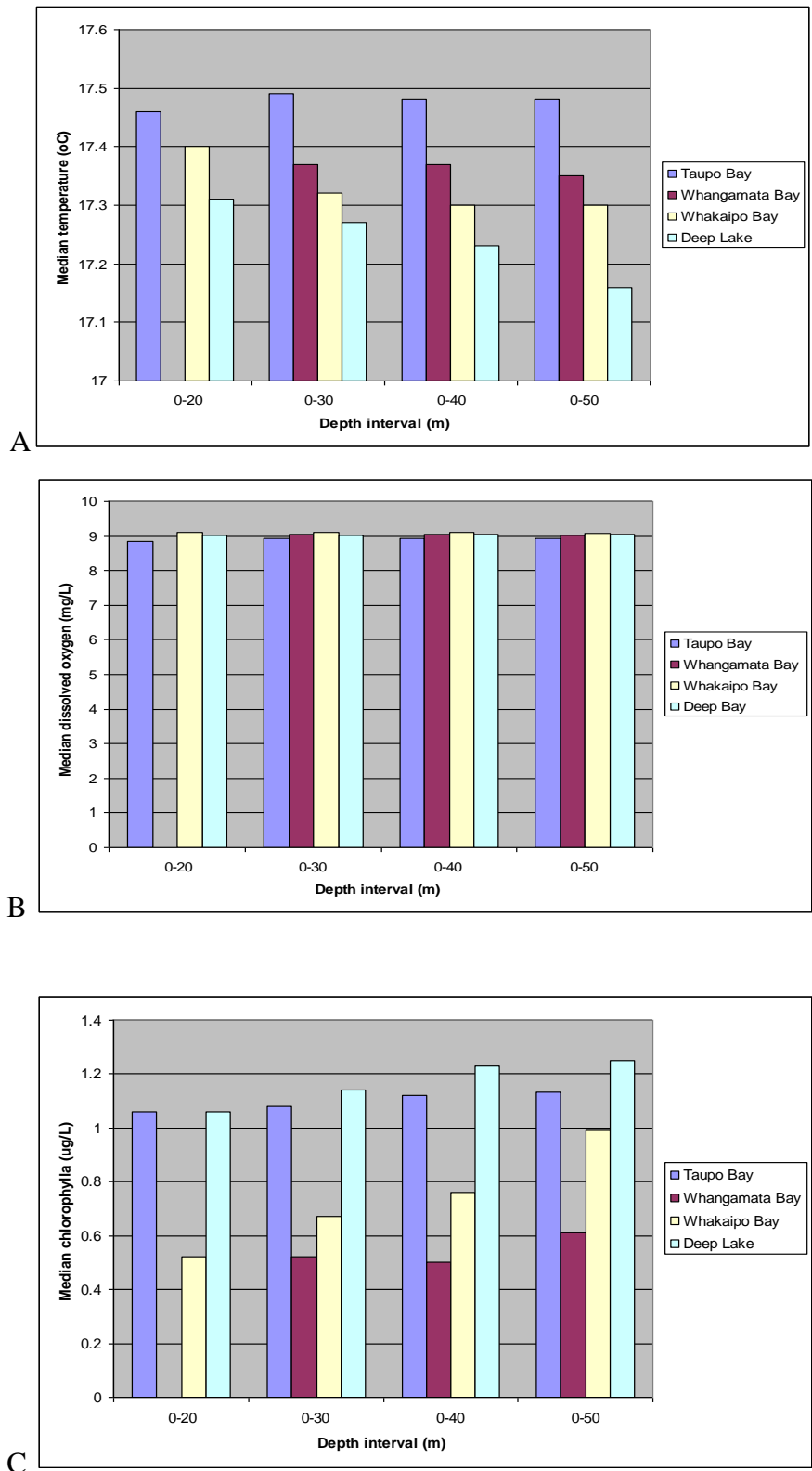


Figure 20. Median A) temperature, B) dissolved oxygen, and C) chlorophyll fluorescence from the BioFish survey of 16-03-06 grouped by lake bed depth for the bays and grouped by sample depth for the deep lake.

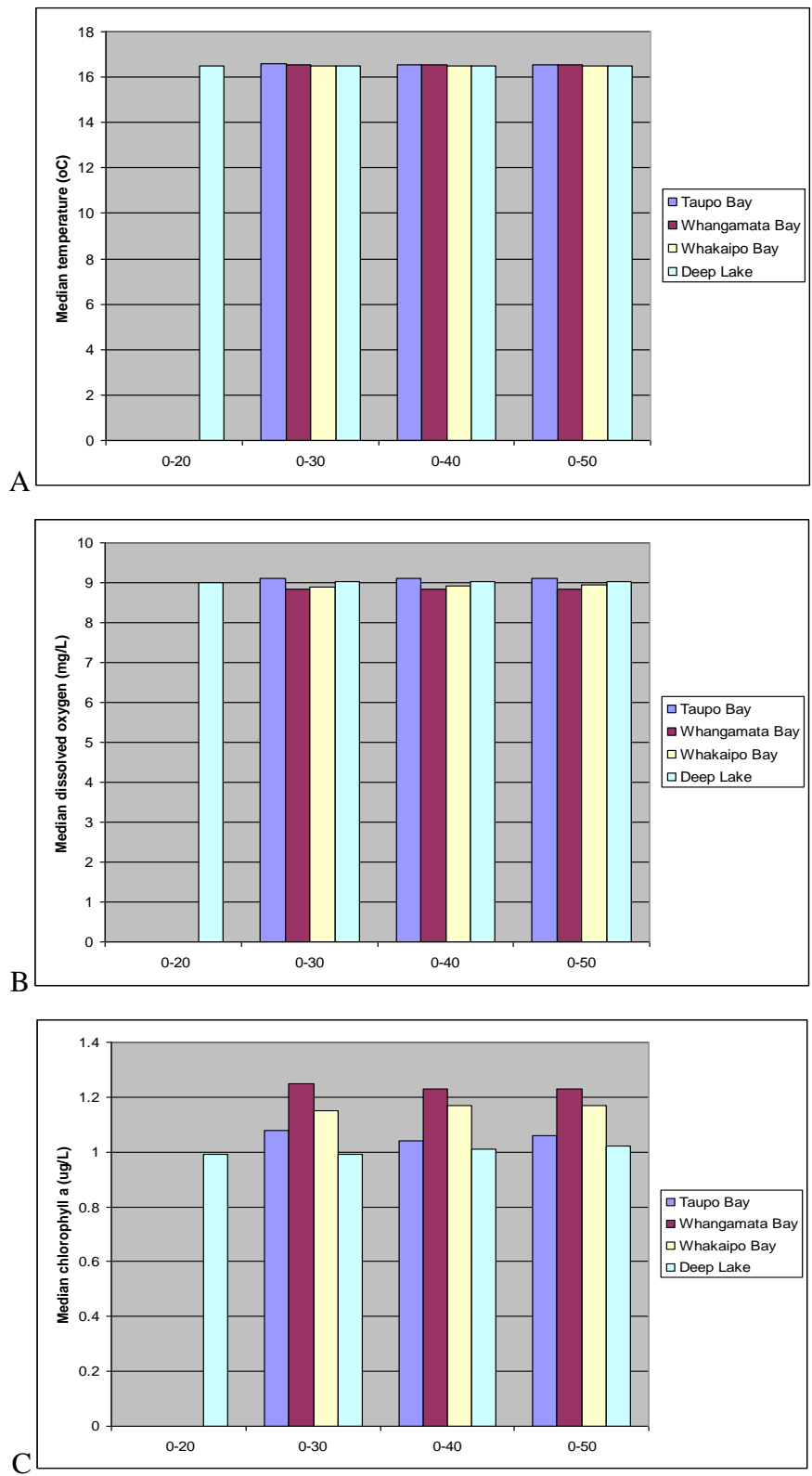


Figure 21. Median A) temperature, B) dissolved oxygen, and C) chlorophyll fluorescence from the BioFish survey of 19-04-06, grouped by lake bed depth for the bays and grouped by sample depth.

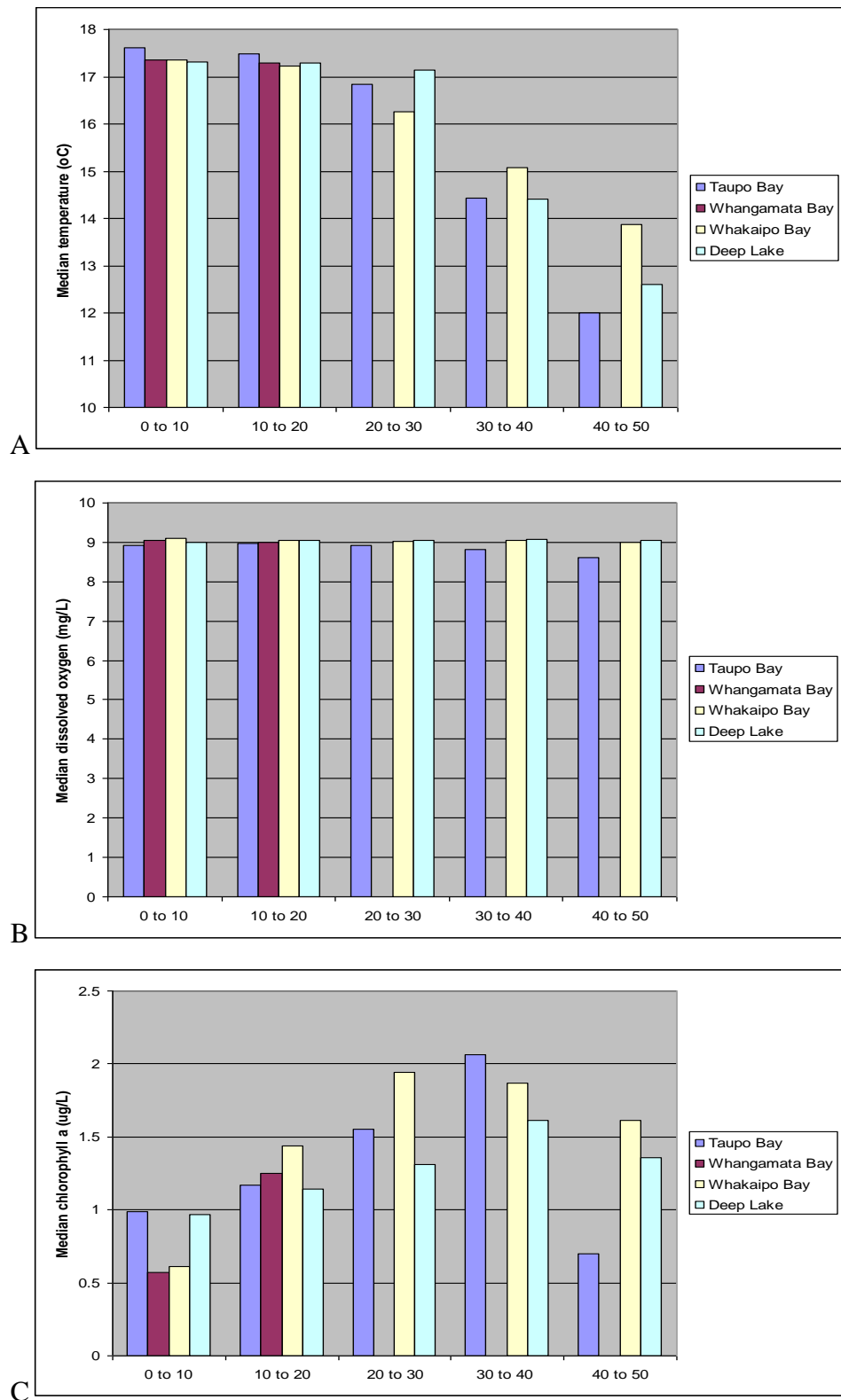


Figure 22. Median A) temperature, B) dissolved oxygen, and C) chlorophyll fluorescence from the BioFish survey of 16-03-06, grouped by sample depth.

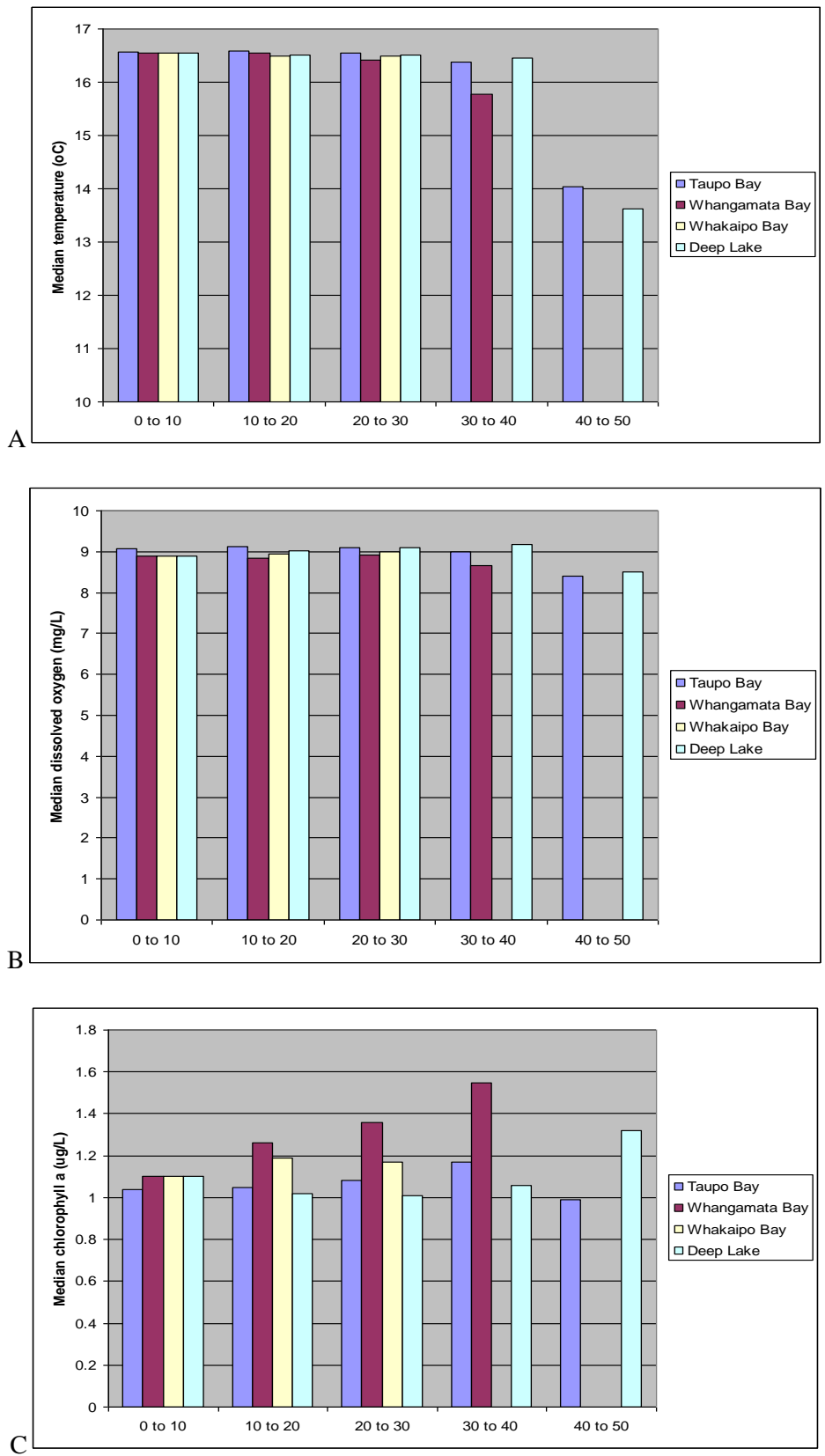


Figure 23. Median A) temperature, B) dissolved oxygen, and C) chlorophyll fluorescence from the BioFish survey of 19-04-06, grouped by sample depth.

3. Discussion

The deep chlorophyll maximum (DCM) situated around 45 m was again a prominent feature of distribution of phytoplankton distributions in Lake Taupo, but was less evident in the southern part of the lake than in the north, and was less evident than in the BioFish survey of 2004-5 (Hamilton *et al.* 2005). The reasons for differences between basins and between years are not clear. It is possible that large, plunging inflows could partially disrupt the formation of the DCM in the southern basin.

Hamilton *et al.* (2005) indicated that the depth and 'strength' (i.e. concentration) of the DCM could be a useful indicator to the health of Lake Taupo but more information is probably needed to develop an inventory of information for DCM depth and strength in relation to various environmental factors, e.g., nutrients, light attenuation, temperature magnitude and vertical structure, and meteorological factors. Nevertheless we still hypothesise that features of the DCM could be a valuable complement to other physical and chemical measures that are designed to indicate the long-term health of Lake Taupo (e.g., Gibbs, 2004). For example, the DCM appears to have disappeared from Lake Rotoiti and been replaced by surface-dominated phytoplankton populations in summer, whereas the DCM usually occurs during the summer stratified season in Lake Tarawera, where its depth generally varies between 20 and 25 m, and the DCM is well defined in Lake Rotoma, where its depth is usually between 25 and 25 m. In each of these cases the position of the DCM is very closely tied to the light (irradiance) and it forms where irradiance is around 1-2 % of values at the water surface. The position of the DCM appeared to be more closely tied to the 1-2 % irradiance level than to the thermocline depth, though the presence of vertical stratification and the formation of the DCM in a region where temperature changes rapidly with depth also appear to be a prerequisite for DCM formation.

A useful recent complement to Environment Waikato's routine Lake Taupo monitoring programme contracted to the National Institute of Water and Atmosphere Ltd (NIWA) is the addition of measurements of vertical distributions of irradiance. These measurements are complementary to Secchi depth measurements for water clarity, but provide a more definitive method to evaluate how irradiance changes through the water column. It will be useful to use these data to further test that the DCM forms where irradiance is 1-2 % of surface values, and to

then speculate on what levels of phytoplankton in surface waters could shift and potentially disrupt the DCM, i.e., shift the 1-2 % light level above the major temperature gradient (the metalimnion); in a situation analogous to Lake Rotoiti. There is no immediate threat of this occurrence but it will nevertheless be useful to read any tell-tale signs of changes in irradiance profiles and position of the DCM.

Analogies have previously been drawn between Lake Tahoe (Nevada, USA) and Lake Taupo (Edgar, 1999). Both lakes are oligotrophic (low productivity waters) and both appear to be subject to gradual eutrophication, with similar concerns about effects of land use. The lakes differ somewhat in hydrology, however, as the water residence time in Lake Tahoe is around 600 years whereas it is around 10-11 years in Lake Taupo, and Lake Tahoe is also much deeper at 501 m. In Lake Tahoe, 50 years of Secchi depth readings support a clear trend of decreasing water clarity in the lake, at least until recently. This trend only becomes evident when the full complement of data is examined, whereas subsets of the data of up to a decade in duration may variously provide trends ranging from increasing, no change, or decreasing water clarity. Thus it is important to keep developing the inventory of both Secchi depth and irradiance profile measurements in Lake Taupo as we attempt to identify long-term trends, including statistical measures of variability of clarity, as there are suggestions that there has been greater variability of water clarity in Lake Taupo in recent years.

At a local level, comparisons could be made with other lakes where there are DCMs, e.g., Lake Tarawera and Lake Rotoma amongst the Rotorua lakes, and also Lake Waikaremoana. Howard-Williams *et al.* (1986) identified a DCM in Lake Waikaremoana, a lake subject to large and often rapid fluctuations in water clarity. These authors indicated that Waikaremoana was therefore a fragile system in which the rapid changes in light regime had the potential to have major effects on the ecology of the lake, notably on the phytoplankton communities. Notably, if the 1-2 % light level was displaced to be well above the thermocline, then Howard-Williams *et al.* (1986) suggested that the DCM would no longer persist. There is anecdotal information that would support validation of this hypothesis in that Lake Waikaremoana has recently been subject to high turbidity associated with a major flood event, which appears to have disrupted the DCM and may ultimately be linked to the recent poor condition of trout in open waters of the lake (R. Pitkethley, Eastern Fish & Game, pers. comm.). While Lake Taupo is not subject to the same high degree of

variability of water clarity as Lake Waikaremoana, it is still subject to localised runoff events that can reduce water clarity in bays. Clearly, therefore, vigilance is still required to protect these areas by ensuring that the landscape is not altered in a way that would increase erosion of fine sediments into the lake.

One of the most marked seasonal features of our study is the rapid increase in chlorophyll concentrations in May followed by a peak throughout the water column in July, when the lake is fully mixed. This observation fits with earlier studies (e.g. Vincent, 1983) which have shown that the depth integrated production and biomass of phytoplankton in Lake Taupo may be up to ten-fold higher in winter than in summer, stimulated by mixing of nutrients from deeper in the lake where these nutrients were previously unavailable due to summer stratification. Vincent (1983) also carefully demonstrated that despite entrainment of phytoplankton through the entire depth of the water column in winter, there may still be sufficient light for them to respond to the additional nutrient supply and to increase their biomass to obtain an annual maximum in winter. There was some evidence that diatoms, e.g. *Fragillaria crotonensis*, *Aulocoseira granulata*, and *Asterionella formosa*, had increased in biomass through the winter period though there tended to be a greater number of green algae (chlorophytes) than had been observed previously in winter by Vincent (1983), and there was considerable variation between stations. In the stratified period green algae and blue-green algae (cyanobacteria) were co-dominant, varying between stations but mostly occurring at low densities. There is no clear trend of differences in species composition between bays and the mid-lake station. It should be noted that our sampling did not specifically target species at the DCM as it was confined to the surface and a depth of 15 m.

Comparisons of temperature and chlorophyll fluorescence between bays and central lake stations indicate that bays warm during daytime to a slightly greater extent than in the central lake; correspondingly they will cool to a greater extent and therefore be exposed to a greater overall range of water temperature. These temperature variations could be expected to lead to a greater degree of convective mixing which may in turn lead to greater nutrient resupply in bays compared with the central lake. Other contributors to greater nutrient supply in bays may relate to proximity of bays to nutrients entering the lake via land runoff, as well as potential for internal waves centred at the thermocline to break on shallow areas of sloping lakebed, and thereby transfer nutrients to surface waters. In the BioFish temperature plot of Fig. 4D, for example,

there is evidence in that the thermocline has tilted and there will be a restoring force acting to create an internal wave. Under extreme circumstances these internal waves can exceed 50 m and may result in intrusions of cold bottom waters (the hypolimnion) right to the water surface. Overall, it is these factors related to nutrient resupply that may contribute to high chlorophyll fluorescence in the bays compared with the central lake station.

Our results continue to suggest that the formation of a DCM and its relationship with the high water clarity in Lake Taupo are an important aspect of the ecology of the lake. There are differences in temperature and chlorophyll between the central lake and bays in Lake Taupo that are consistent with greater diurnal heating and cooling in bays, and with greater nutrient resupply to bays, respectively. It would be useful to now compare earlier data (e.g. Vincent, 1983) with more recent data such as presented in this report and collected by Environment Waikato, to examine statistically whether there have been significant inter-annual changes and in the seasonality of water clarity, temperature and chlorophyll in Lake Taupo.

4. Acknowledgements

We acknowledge the support of the Lakes and Waterways Action Group (LWAG) in providing funding for this project. The Taupo Harbourmasters, Brent McIntosh and Les Porter, are acknowledged for their invaluable contribution to the collection of the BioFish data. We thank David Klee for field assistance.

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6. Appendix

Table 4. Temperature, chlorophyll *a* and dissolved oxygen in shallow bays, survey of 16-03-06 grouped by lake bed depth.

BioFish measurement 16-03-06

Taupo Bay

Lake bed depth (all less than or equal to)		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
20m	Average	17.46	1.15	8.83
20m	Median	17.46	1.06	8.85
20m	Standard Deviation	0.02	0.66	0.07
20m	Sample size (n)	50	50	50
30m	Average	17.49	1.13	8.92
30m	Median	17.49	1.08	8.93
30m	Standard Deviation	0.15	0.39	0.08
30m	Sample size (n)	253	253	253
40m	Average	17.23	1.26	8.93
40m	Median	17.48	1.12	8.94
40m	Standard Deviation	0.7	0.52	0.07
40m	Sample size (n)	575	575	575

Whangamata Bay		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
20m	Average	no data	no data	no data
20m	Median	no data	no data	no data
20m	Standard Deviation	no data	no data	no data
20m	Sample size (n)	no data	no data	no data
30m	Average	17.36	0.6	8.81
30m	Median	17.37	0.52	9.034
30m	Standard Deviation	0.03	0.3	1.13
30m	Sample size (n)	53	53	52
40m	Average	17.36	0.56	8.87
40m	Median	17.37	0.5	9.06
40m	Standard Deviation	0.03	0.27	1.42
40m	Sample size (n)	72	72	71
50m	Average	17.35	0.7	8.75
50m	Median	17.35	0.61	9.01
50m	Standard Deviation	0.05	0.36	1.88
50m	Sample size (n)	142	142	141

Whakaipo Bay		Temperature (°C)	Chlorophyll (µg/L)	<i>a</i>	Dissolved Oxygen (mg/L)
20m	Average	17.41	0.55		9.09
20m	Median	17.4	0.52		9.1
20m	Standard Deviation	0.07	0.26		0.04
20m	Sample size (n)	49	49		49
30m	Average	17.32	0.85		9.08
30m	Median	17.32	0.67		9.1
30m	Standard Deviation	0.14	0.51		0.1
30m	Sample size (n)	135	135		135
40m	Average	17.31	0.91		9.08
40m	Median	17.3	0.76		9.1
40m	Standard Deviation	0.12	0.5		0.1
40m	Sample size (n)	187	187		187
50m	Average	16.98	1.08		9.06
50m	Median	17.29	0.99		9.08
50m	Standard Deviation	0.83	0.6		0.09
50m	Sample size (n)	253	253		253

Table 5. Temperature, chlorophyll *a* and dissolved oxygen in the deep lake, survey of 16-03-06 grouped by sample depth.

Deep lake		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
20m	Average	17.34	1.12	9
20m	Median	17.31	1.06	9.02
20m	Standard Deviation	0.12	0.7	0.19
20m	Sample size (n)	1445	1445	1445
30m	Average	17.16	1.25	9.01
30m	Median	17.27	1.14	9.03
30m	Standard Deviation	0.44	0.92	0.17
30m	Sample size (n)	2248	2248	2248
40m	Average	16.48	1.35	9.01
40m	Median	17.23	1.23	9.04
40m	Standard Deviation	1.34	0.84	0.22
40m	Sample size (n)	3117	3117	3117
50m	Average	15.88	1.36	9.01
50m	Median	17.16	1.25	9.04
50m	Standard Deviation	1.88	0.8	0.27
50m	Sample size (n)	3683	3683	3683

Table 6. Temperature, chlorophyll *a* and dissolved oxygen in shallow bays, survey of 19-04-06 grouped by lake bed depth (Lake Taupo).

BioFish measurement 19-04-06, Taupo Bay				
Lake bed depth (all less than or equal to)		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
20m	Average	no data	no data	no data
20m	Median	no data	no data	no data
20m	Standard Deviation	no data	no data	no data
20m	Sample size (n)	no data	no data	no data
30m	Average	16.56	1.26	9.09
30m	Median	16.57	1.08	9.1
30m	Standard Deviation	0.03	0.99	0.05
30m	Sample size (n)	232	232	232
40m	Average	16.54	1.21	9.1
40m	Median	16.56	1.04	9.11
40m	Standard Deviation	0.05	1.14	0.22
40m	Sample size (n)	527	527	527
50m	Average	16.47	1.2	9.07
50m	Median	16.56	1.06	9.1
50m	Standard Deviation	0.39	1.04	0.23
50m	Sample size (n)	649	649	649
<hr/>				
Whangamata Bay		Temperature (°C)	Chlorophyll (µg/L)	<i>a</i> Dissolved (mg/L) Oxygen
20m	Average	no data	no data	no data
20m	Median	no data	no data	no data
20m	Standard Deviation	no data	no data	no data
20m	Sample size (n)	no data	no data	no data
30m	Average	16.54	1.3	8.86
30m	Median	16.54	1.25	8.85
30m	Standard Deviation	0.01	0.29	0.17
30m	Sample size (n)	209	209	209
40m	Average	16.51	1.29	8.85
40m	Median	16.54	1.23	8.85
40m	Standard Deviation	1.07	0.3	0.59
40m	Sample size (n)	243	243	243
50m	Average	16.49	1.28	8.86
50m	Median	16.54	1.23	8.85
50m	Standard Deviation	1	0.3	0.55
50m	Sample size (n)	280	280	280
<hr/>				
Whakaipo Bay		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
20m	Average	no data	no data	no data

20m	Median	no data	no data	no data
20m	Standard Deviation	no data	no data	no data
20m	Sample size (n)	no data	no data	no data
30m	Average	16.5	1.19	8.91
30m	Median	16.5	1.15	8.9
30m	Standard Deviation	1.99	0.21	1.07
30m	Sample size (n)	68	68	68
40m	Average	16.5	1.2	8.93
40m	Median	16.5	1.17	8.93
40m	Standard Deviation	1.47	0.25	0.8
40m	Sample size (n)	125	125	125
50m	Average	16.5	1.39	8.94
50m	Median	16.5	1.17	8.94
50m	Standard Deviation	1.21	1.76	0.66
50m	Sample size (n)	185	185	185

Table 7. Statistics on temperature, chlorophyll *a* and dissolved oxygen in the deep lake, survey of 19-04-06 grouped by sample depth (Lake Taupo).

Deep lake		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
20m	Average	16.52	1.05	8.99
20m	Median	16.51	0.99	9
20m	Standard Deviation	0.39	0.88	0.3
20m	Sample size (n)	1803	1803	1803
30m	Average	16.51	1.05	9.02
30m	Median	16.51	0.99	9.03
30m	Standard Deviation	0.33	0.77	0.26
30m	Sample size (n)	2562	2562	2562
40m	Average	16.42	1.08	9.02
40m	Median	16.5	1.01	9.04
40m	Standard Deviation	0.48	0.75	0.27
40m	Sample size (n)	3210	3210	3210
50m	Average	16.1	1.11	8.97
50m	Median	16.5	1.02	9.03
50m	Standard Deviation	0.99	0.72	0.26
50m	Sample size (n)	3659	3659	3659

Table 8. Temperature, chlorophyll *a* and dissolved oxygen in shallow bays, survey of 2006-03-16 grouped by sample depth.

BioFish measurement				
16-03-06 Taupo Bay				
Sample depth (all less than or equal to)		Temp. (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
0 > sample depth <= 10m	Average	17.6	1.05	8.93
0 > sample depth <= 10m	Median	17.61	0.99	8.93
0 > sample depth <= 10m	Standard Deviation	0.11	0.36	0.05
0 > sample depth <= 10m	Sample size (n)	253	253	253
10 > sample depth <= 20m	Average	17.43	1.22	8.95
10 > sample depth <= 20m	Median	17.48	1.17	8.96
10 > sample depth <= 20m	Standard Deviation	0.18	0.37	0.08
10 > sample depth <= 20m	Sample size (n)	224	224	224
20m > sample depth <=30m	Average	16.72	1.63	8.91
20m > sample depth <=30m	Median	16.84	1.55	8.92
20m > sample depth <=30m	Standard Deviation	0.58	0.65	0.08
20m > sample depth <=30m	Sample size (n)	120	120	120
30m > sample depth <=40m	Average	14.22	2.05	8.83
30m > sample depth <=40m	Median	14.43	2.06	8.82
30m > sample depth <=40m	Standard Deviation	0.74	0.54	0.1
30m > sample depth <=40m	Sample size (n)	54	54	54
40m > sample depth <=50m	Average	12	0.78	8.65
40m > sample depth <=50m	Median	12.01	0.7	8.6
40m > sample depth <=50m	Standard Deviation	0.22	0.2	0.12
40m > sample depth <=50m	Sample size (n)	8	8	8
		Temperature	Chlorophyll	Dissolved Oxygen
Whangamata Bay		(°C)	<i>a</i> (µg/L)	(mg/L)
0 > sample depth <= 10m	Average	17.35	0.63	8.96
0 > sample depth <= 10m	Median	17.35	0.57	9.04
0 > sample depth <= 10m	Standard Deviation	0.04	0.29	0.7
0 > sample depth <= 10m	Sample size (n)	105	105	105
10 > sample depth <= 20m	Average	17.27	1.31	8.67
10 > sample depth <= 20m	Median	17.28	1.25	9
10 > sample depth <= 20m	Standard Deviation	0.02	0.24	1
10 > sample depth <= 20m	Sample size (n)	18	18	18
20m > sample depth <=30m	Average	no data	no data	no data
20m > sample depth <=30m	Median	no data	no data	no data
20m > sample depth <=30m	Standard Deviation	no data	no data	no data
20m > sample depth <=30m	Sample size (n)	no data	no data	no data
30m > sample depth <=40m	Average	no data	no data	no data

30m > sample depth <=40m	Median	no data	no data	no data
30m > sample depth <=40m	Standard Deviation	no data	no data	no data
30m > sample depth <=40m	Sample size (n)	no data	no data	no data
40m > sample depth <=50m	Average	no data	no data	no data
40m > sample depth <=50m	Median	no data	no data	no data
40m > sample depth <=50m	Standard Deviation	no data	no data	no data
40m > sample depth <=50m	Sample size (n)	no data	no data	no data

Whakaipo Bay		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
0 > sample depth <= 10m	Average	17.36	0.65	9.1
0 > sample depth <= 10m	Median	17.35	0.61	9.1
0 > sample depth <= 10m	Standard Deviation	0.06	0.31	0.05
0 > sample depth <= 10m	Sample size (n)	127	127	127
10 > sample depth <= 20m	Average	17.21	1.43	9.03
10 > sample depth <= 20m	Median	17.23	1.44	9.06
10 > sample depth <= 20m	Standard Deviation	0.08	0.29	0.13
10 > sample depth <= 20m	Sample size (n)	71	71	71
20m > sample depth <=30m	Average	16.31	1.87	9.01
20m > sample depth <=30m	Median	16.26	1.94	9.03
20m > sample depth <=30m	Standard Deviation	0.48	0.32	0.07
20m > sample depth <=30m	Sample size (n)	21	21	21
30m > sample depth <=40m	Average	14.9	1.94	9.02
30m > sample depth <=40m	Median	15.07	1.87	9.05
30m > sample depth <=40m	Standard Deviation	0.56	0.29	0.1
30m > sample depth <=40m	Sample size (n)	22	22	22
40m > sample depth <=50m	Average	13.87	1.58	9
40m > sample depth <=50m	Median	13.88	1.61	9.01
40m > sample depth <=50m	Standard Deviation	0.04	0.11	0.01
40m > sample depth <=50m	Sample size (n)	3	3	3

Deep lake		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
0 > sample depth <= 10m	Average	17.38	1	8.99
0 > sample depth <= 10m	Median	17.32	0.97	9
0 > sample depth <= 10m	Standard Deviation	0.13	0.48	0.22
0 > sample depth <= 10m	Sample size (n)	646	646	646
10 > sample depth <= 20m	Average	17.3	1.22	9.01
10 > sample depth <= 20m	Median	17.3	1.14	9.04
10 > sample depth <= 20m	Standard Deviation	0.09	0.83	0.17
10 > sample depth <= 20m	Sample size (n)	799	799	799
20m > sample depth <=30m	Average	16.84	1.47	9.02
20m > sample depth <=30m	Median	17.15	1.31	9.04
20m > sample depth <=30m	Standard Deviation	0.61	1.18	0.13

20m > sample depth <=30m	Sample size (n)	803	803	803
30m > sample depth <=40m	Average	14.71	1.63	9.03
30m > sample depth <=40m	Median	14.41	1.61	9.08
30m > sample depth <=40m	Standard Deviation	1.28	0.52	0.32
30m > sample depth <=40m	Sample size (n)	869	869	869
40m > sample depth <=50m	Average	12.57	1.38	8.99
40m > sample depth <=50m	Median	12.61	1.36	9.05
40m > sample depth <=50m	Standard Deviation	0.4	0.47	0.43
40m > sample depth <=50m	Sample size (n)	566	566	566

Table 9. Statistics on temperature, chlorophyll *a* and dissolved oxygen in the deep lake, survey of 19-04-06 grouped by sample depth interval.

BioFish measurement				
19-04-06 Taupo Bay				
Sample depth		Temp. (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
(all less than or equal to)				
0 > sample depth <= 10m	Average	16.56	1.18	9.05
0 > sample depth <= 10m	Median	16.56	1.04	9.06
0 > sample depth <= 10m	Standard Deviation	0.02	0.76	0.32
0 > sample depth <= 10m	Sample size (n)	214	214	214
10 > sample depth <= 20m	Average	16.57	1.09	9.13
10 > sample depth <= 20m	Median	16.58	1.05	9.12
10 > sample depth <= 20m	Standard Deviation	0.02	0.26	0.05
10 > sample depth <= 20m	Sample size (n)	186	186	186
20m > sample depth <=30m	Average	16.53	1.37	9.11
20m > sample depth <=30m	Median	16.54	1.08	9.11
20m > sample depth <=30m	Standard Deviation	0.05	1.9	0.07
20m > sample depth <=30m	Sample size (n)	151	151	151
30m > sample depth <=40m	Average	16.24	1.3	8.94
30m > sample depth <=40m	Median	16.38	1.17	8.99
30m > sample depth <=40m	Standard Deviation	0.33	0.4	0.16
30m > sample depth <=40m	Sample size (n)	48	48	48
40m > sample depth <=50m	Average	14.04	1.04	8.4
40m > sample depth <=50m	Median	14.03	0.99	8.41
40m > sample depth <=50m	Standard Deviation	0.62	0.17	0.19
40m > sample depth <=50m	Sample size (n)	14	14	14
		Temperature (°C)	Chlorophyll <i>a</i> (µg/L)	Dissolved Oxygen (mg/L)
Whangamata Bay				
0 > sample depth <= 10m	Average	16.55	1.1	8.88
0 > sample depth <= 10m	Median	16.55	1.1	8.88
0 > sample depth <= 10m	Standard Deviation	0.01	0.2	0.23
0 > sample depth <= 10m	Sample size (n)	62	62	62
10 > sample depth <= 20m	Average	16.54	1.31	8.85
10 > sample depth <= 20m	Median	16.54	1.26	8.84
10 > sample depth <= 20m	Standard Deviation	0	0.29	0.13
10 > sample depth <= 20m	Sample size (n)	180	180	180
20m > sample depth <=30m	Average	16.36	1.39	8.92
20m > sample depth <=30m	Median	16.42	1.36	8.92
20m > sample depth <=30m	Standard Deviation	0.16	0.17	0.09

20m > sample depth <=30m	Sample size (n)	20	20	20
30m > sample depth <=40m	Average	15.66	1.56	8.65
30m > sample depth <=40m	Median	15.77	1.55	8.66
30m > sample depth <=40m	Standard Deviation	0.4	0.26	0.15
30m > sample depth <=40m	Sample size (n)	12	12	12
40m > sample depth <=50m	Average	no data	no data	no data
40m > sample depth <=50m	Median	no data	no data	no data
40m > sample depth <=50m	Standard Deviation	no data	no data	no data
40m > sample depth <=50m	Sample size (n)	no data	no data	no data

		Temperature	Chlorophyll <i>a</i>	Dissolved Oxygen
		(°C)	(µg/L)	(mg/L)
Whakaipo Bay				
0 > sample depth <= 10m	Average	16.55	1.1	8.88
0 > sample depth <= 10m	Median	16.55	1.1	8.88
0 > sample depth <= 10m	Standard Deviation	0.01	0.2	0.23
0 > sample depth <= 10m	Sample size (n)	62	62	62
10 > sample depth <= 20m	Average	16.5	1.6	8.94
10 > sample depth <= 20m	Median	16.5	1.19	8.94
10 > sample depth <= 20m	Standard Deviation	0.01	2.46	0.02
10 > sample depth <= 20m	Sample size (n)	62	62	62
20m > sample depth <=30m	Average	16.49	1.18	8.99
20m > sample depth <=30m	Median	16.49	1.17	9
20m > sample depth <=30m	Standard Deviation	0.01	0.21	0.02
20m > sample depth <=30m	Sample size (n)	36	36	36
30m > sample depth <=40m	Average	no data	no data	no data
30m > sample depth <=40m	Median	no data	no data	no data
30m > sample depth <=40m	Standard Deviation	no data	no data	no data
30m > sample depth <=40m	Sample size (n)	no data	no data	no data
40m > sample depth <=50m	Average	no data	no data	no data
40m > sample depth <=50m	Median	no data	no data	no data
40m > sample depth <=50m	Standard Deviation	no data	no data	no data
40m > sample depth <=50m	Sample size (n)	no data	no data	no data

		Temperature	Chlorophyll <i>a</i>	Dissolved Oxygen
		(°C)	(µg/L)	(mg/L)
Deep lake				
0 > sample depth <= 10m	Average	16.55	1.1	8.88
0 > sample depth <= 10m	Median	16.55	1.1	8.88
0 > sample depth <= 10m	Standard Deviation	0.01	0.2	0.23
0 > sample depth <= 10m	Sample size (n)	62	62	62
10 > sample depth <= 20m	Average	16.52	1.08	9.02
10 > sample depth <= 20m	Median	16.51	1.02	9.03
10 > sample depth <= 20m	Standard Deviation	0.53	0.47	0.36
10 > sample depth <= 20m	Sample size (n)	982	982	982

20m > sample depth <=30m	Average	16.5	1.06	9.11
20m > sample depth <=30m	Median	16.51	1.01	9.11
20m > sample depth <=30m	Standard Deviation	0.05	0.39	0.06
20m > sample depth <=30m	Sample size (n)	759	759	759
		Temperature	Chlorophyll <i>a</i>	Dissolved Oxygen
		(°C)	(µg/L)	(mg/L)
30m > sample depth <=40m	Average	16.04	1.19	9.01
30m > sample depth <=40m	Median	16.46	1.06	9.17
30m > sample depth <=40m	Standard Deviation	0.74	0.67	0.3
30m > sample depth <=40m	Sample size (n)	648	648	648
40m > sample depth <=50m	Average	13.82	1.31	8.57
40m > sample depth <=50m	Median	13.62	1.32	8.51
40m > sample depth <=50m	Standard Deviation	0.97	0.33	0.23
40m > sample depth <=50m	Sample size (n)	449	449	449
