Artificial mixing in Lake Rotoehu: physico-chemical effects

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Executive summary

Lake Rotoehu is a moderately large, shallow, polymictic lake in the Rotorua/Te Arawa lakes district. The lake was historically fairly productive, with algal blooms observed as early as the 1960s, and the lake is generally considered to have been mesotrophic until about 1993 (BoPRC 2007). Since that time, a combination of land use intensification, water level changes, and nutrient-rich geothermal inflows have likely contributed to increases in productivity, with moderate to severe blooms of cyanobacteria recorded nearly every year for the past 20 years. These blooms are often strongest during periodic thermal stratification events in warm, calm weather.

During stratification events, heated surface waters become isolated from deep waters due to a density gradient. Deep water becomes hypoxic due to consumption of oxygen by the breakdown of organic matter, and there is increased release of nutrients bound to lake sediments, to the overlying water column. This 'internal nutrient load' contributes to phytoplankton growth once the water column is mixed by cooler and/or windier weather. Blooms of phytoplankton driven by increased nutrient supply have negative effects on water quality and biodiversity in the lake, thus reducing its economic, recreational and/or cultural values.

Bay of Plenty Regional Council (BoPRC) is charged with maintaining the ecosystem health of Lake Rotoehu, and in 2007 published the Lake Rotoehu Action Plan, outlining multiple restoration initiatives to reduce nutrient loading in the lake. Action Plan initiatives have included constructed/floating wetlands, riparian protection, improvement of land use practices, hornwort harvesting and alum dosing of inflowing geothermal water. The present report evaluates the effects of an in-lake technique to improve water quality. Two artificial water column mixing devices were deployed in Rotoehu from November 2012 to June 2013 (and are ongoing). These devices force air through a diffuser near the lake bottom. Buoyancy caused by the bubbles draws water from the bottom of the lake up through large vertical cylinders, where the water is subsequently directed horizontally across the surface of the lake. The University of Waikato (UoW) was contracted to monitor the extent of the effects of the mixing devices on the physical (temperature and dissolved oxygen), chemical (nutrients), and biological (phytoplankton and zooplankton) qualities of the lake. This work encompassed the use of a range of instrumentation, lab analyses, and species enumeration of water samples. The present report presents the monitoring of historical (BoPRC) and recent (UoW) physical and chemical parameters, and a companion report will address the results of the biodiversity surveys.

Although local effects on the thermal profile of the water column were observed adjacent to the mixing devices, modification of temperature dynamics in Lake Rotoehu

did not reach great horizontal extent over the observation period. Interpretation of this monitoring study is confounded somewhat by the period prior to installation of the machines being unusually cold and windy, and the period of device deployment being unusually hot and dry. In fact, over the summer when the devices were installed, Lake Rotoehu was stratified more often and more strongly than the previous (pre-installation) summer. Additional complications with the devices and specific considerations for Lake Rotoehu are discussed.

Promisingly, water sample results clearly indicate that nutrient concentrations, water clarity, and trophic status in Rotoehu have all improved over the past few years (although they have not yet reached the Trophic Level Index (TLI) target of the Rotoehu Action Plan). Notably, water quality in 2012/2013 was relatively good despite the presence of sustained and stable periods of stratification and significant oxygen depletion in bottom waters. This suggests that the management of external nutrient inputs may be the most effective means of improving water quality in Lake Rotoehu, and other restoration initiatives undertaken by BoPRC, landowners, and the community may already be having a positive impact on lake water quality. Further monitoring over coming years will help to clarify these observations.

Acknowledgements

We acknowledge the valuable contributions of Max Gibbs and NIWA, as well as Andy Bruere and John McIntosh and BoPRC. Field assistance was ably provided by Joseph Butterworth. We acknowledge the contribution of BoPRC's Environmental Data Survey team who collect and process monthly lake monitoring, and specifically Paul Scholes, for providing the data.

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Introduction

Threats to lake systems

Lake ecosystems provide many valuable services, including water regulation, nutrient cycling, supply of food resources, cultural and conservation values. Healthy lake systems often have improved economic and cultural contributions through increased property values, income from recreation and tourism, and maintenance of intrinsic and aesthetic values of pristine natural systems. Changes in human land use in lake catchments can accelerate the process of eutrophication, thus reducing the ability of ecosystems to provide these services.

Aquatic ecosystem health is threatened by increases in external nutrient loads associated with catchment land uses including agriculture and urban development. Nitrogen and phosphorus runoff above natural (non-anthropogenic) levels can alter the trophic state of lakes, in many cases shifting them from conditions of low to higher productivity and trophic state ('eutrophication'). Eutrophic systems are typified by poor water quality and blooms of cyanobacteria that reduce ecosystem services and can be a threat to human and animal health.

In eutrophic systems, thermal stratification can increase the 'internal load' of nutrients. Stratification occurs when surface waters (epilimnion) are warmed by the sun, forming a layer above colder, denser water near the lake bottom (hypolimnion). During periods of warm, still weather, this density gradient prevents mixing of surface and bottom waters. Respiration of organisms during decomposition of organic matter in the isolated hypolimnion consumes dissolved oxygen, and once bottom waters are hypoxic or anoxic, phosphate bound to the sediment is released into the water column and ammonium also builds up with hindrance of nitrification. These nutrients can support additional growth of phytoplankton, particularly as nutrients are redistributed through the euphotic zone. Furthermore, isolation of surface waters can provide competitive advantages to cyanobacteria, whose buoyancy, high growth rates at warm temperatures, and capacity to utilise atmospheric nitrogen for growth (Oliver et al. 2012).

Lake Rotoehu

Rotoehu is a moderate sized (795 ha) lake in the northeast of the Rotorua/Te Arawa lakes district. Inflow to the lake is from surface streams and geothermal springs (Donovan, 2003). Geothermal waters contribute dissolved nitrogen and phosphorus to the lake, and the trophic state of the lake has historically been classified as mesotrophic. “Rotoehu” means “murky water”, suggesting that under normal conditions, the lake has lower water clarity than surrounding water bodies. The low water clarity in Lake Rotoehu may be partly attributable to the geothermal influx of nutrients, and the shallow morphology of the lake (mean depth 8.2 m) which allows bottom sediments to become suspended in the water column during windy conditions. Lake Rotoehu is polymictic, meaning it stratifies and mixes several times in a year. It has been subject to increased nutrient loading, with elevated Trophic Level Index (Figure 1) and regular cyanobacteria blooms since 1993 (Lake Rotoehu Action Plan 2007).

In recent decades, the lake has shifted to a eutrophic state. An estimated 43% of the Rotoehu catchment land cover is pasture, and this land use among other factors has likely contributed to increasing the Trophic Level Index (TLI) of the lake shifting from the historically mesotrophic value of 3.9, to regularly exceeding 4.5 (Figure 1).

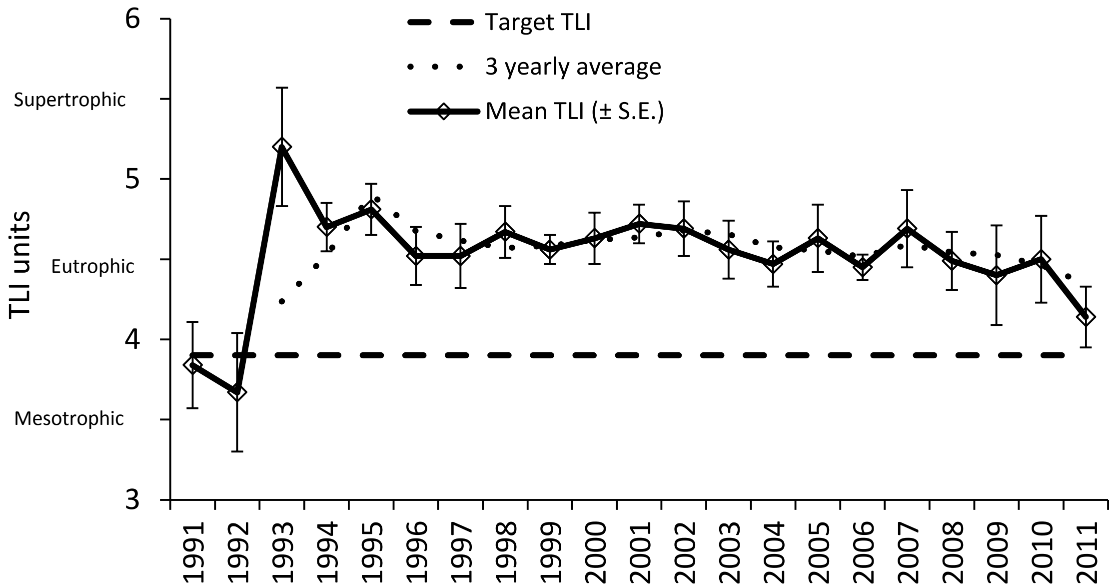

Figure 1. Historical Trophic Level Index (TLI) of Lake Rotoehu from 1991 to 2011 (BoPRC).

BoPRC has undertaken several initiatives to improve the water quality of Lake Rotoehu. These include the improvement of land management practices to reduce nutrient losses from pasture, installation of an alum treatment facility at the soda spring inflow to the lake, construction of a floating wetland and regular harvesting of submerged vegetation (hornwort) from the lake. These combined initiatives coincide with improving water quality from 2007 to present (Figure 1).

Artificial destratification

Despite recent improvements in the water quality of Rotoehu, release during stratification of internal nutrient loads via bottom sediments, and the proliferation of buoyant cyanobacteria during calm stratified periods remain concerns and targets for restoration actions. To that end, BoPRC commissioned the design and installation (Del Monte Ltd engineering) of two aeration/mixing devices For Lake Rotoehu. The devices were designed to increase natural mixing between surface and bottom waters in order to reduce or prevent stratification, and also to reduce occurrences of bottom-water hypoxia. Additionally, increased mixing can reduce accumulations of buoyant cyanobacteria, further mitigating harmful algae blooms.

Two mixing devices were installed in the lake in November 2012. Each consisted of an air compressor driving bubbles through a diffuser, entraining water from the hypolimnion into three columns 2.2 m in diameter with a 5.0 m vertical section. The top of each column had a 90-degree bend to direct the upwelling water horizontally across the lake surface. Each device was theoretically capable of moving 15,000 $m^3 h^{-1}$ of water.

Several studies have evaluated the efficacy and impacts of artificial lake destratification using mathematical modelling and biological surveys (Miles & West, 2011; Toffolon & Serafini, 2013), but few have investigated the effect of artificial mixing on lakes as large as Rotoehu. The University of Waikato (UoW) was contracted to monitor phytoplankton and zooplankton communities concurrently with artificial mixing in Rotoehu. Additionally, UoW researchers used a variety of methods to evaluate the effects of artificial mixing devices on a number of other physical, chemical and biological variables.

This report presents physical and chemical monitoring results in Lake Rotoehu from November 2011 to June 2013, along with recommendations for further data collection and monitoring. A companion report will present the biological monitoring (phytoplankton and zooplankton enumeration). Results from these studies may help inform revision of the current restoration initiatives, and aid the design of similar artificial mixing and nutrient management programs in other lakes.

Methods

Site description

Measurement sites were selected to represent some of the spatial variability around Lake Rotoehu, both nearby, and far from, the two aerators. Figure 2 shows the locations of the water sampling sites and Bio-Fish transect path. Mixing devices were installed centrally in the lake near sites A and E. Site D is also the location of the fixed-sensor monitoring buoy. The water column profiling monitoring buoy was installed approximately 100 m from the southern aerator.

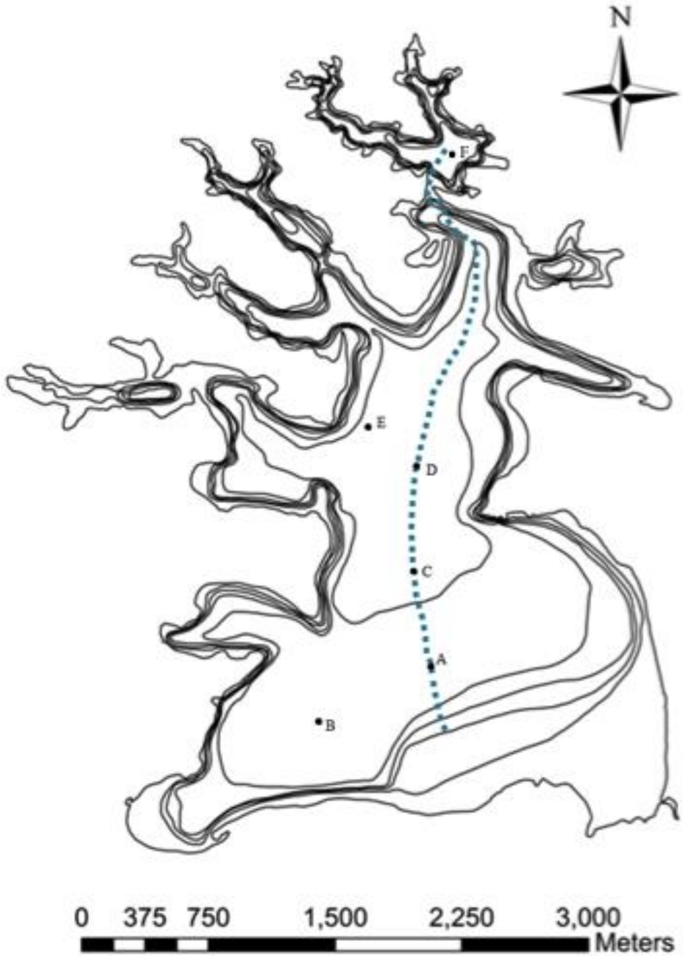

Figure 2. Map of Lake Rotoehu showing sampling locations. Destratification devices are located at sites A and E. Site A is also the location of the profiler buoy, and sampling site #1. B is sampling site #2. Site C is the location of EBoP CTD monitoring. Site D is the site of the monitoring buoy. Additional Secchi depth measurements were taken at site F. The blue dashed line indicates the route taken (South to North) during Bio-Fish surveying.

Meteorology

Meteorological data were obtained from the Rotorua Airport climate station administered by the New Zealand Meteorological Service and obtained via the National Institute of Water and Atmospheric Research's (NIWA) 'cliflo' database (http://cliflo.niwa.co.nz). Daily mean values were calculated from hourly measurements of short wave radiation, air temperature, vapour pressure, wind speed, and daily total rainfall was calculated for rainfall, for the period January 2007 and December 2012.

Monitoring buoy – fixed sensors

UoW and BoPRC installed a water quality monitoring buoy in central Lake Rotoehu in April 2011. The buoy collects quarter-hourly data for meteorological (air temperature, wind speed and direction, humidity, barometric pressure, and rainfall) and water quality (chlorophyll fluorescence, dissolved oxygen, and water temperature) variables. Data are sent via cellular telemetry and posted in near real-time to the Bay of Plenty Regional Council website. The buoy measures water temperature at seven depths, and dissolved oxygen at the surface and bottom of the water column. It thus provides a comprehensive and high-frequency record of thermal and dissolved oxygen dynamics in the lake. The monitoring buoy is located in between the two aerator locations and thus its measurements are not influenced by the environment in the immediate vicinity of either machine.

Water column temperature measurements from the buoy were used to calculate a daily average 'Schmidt Stability Index' using the software 'Lake Analyzer' (Read et al. 2011). This index describes the energy required to mix surface and bottom waters, i.e. the strength of thermal stratification.

Monitoring buoy – Water column profiling sensors

In order to provide further insight into Lake Rotoehu dynamics, and specifically the effects of the aerators on the nearby water column, a second monitoring buoy was installed in June 2013 c. 100 m from site A (Figure 2). The buoy used an automated winch to raise and lower a water quality instrument package in order to measure water temperature, dissolved oxygen, and chlorophyll fluorescence at a two-hour interval and at every 0.5 m through the vertical water column.

CTD Profiles

Water column profiles were taken monthly at sites A and B between December 2011 and January 2013, using a conductivity-temperature-depth (CTD) profiler (SBE 19 plus SEACAT Profiler, Seabird Electronics Inc.), with additional mounted sensors for dissolved oxygen (DO) concentration (Seabird Electronics), chlorophyll fluorescence (Chelsea MiniTracka II) and beam transmittance (WetLabs C-star).

Bio-Fish

The Bio-Fish is a towed probe that measures water temperature, conductivity, dissolved oxygen, chlorophyll fluorescence, and photosynthetically active radiation. The instrument records these values, along with corresponding depth readings and GPS location at a frequency of 4 Hz as it is towed through the water from a boat (Figure 3). As the Bio-Fish moves through the water, it is guided along an undulating path, sampling all depths through the water column. The Bio-Fish transect sampled in Rotoehu is presented in Figure 2.

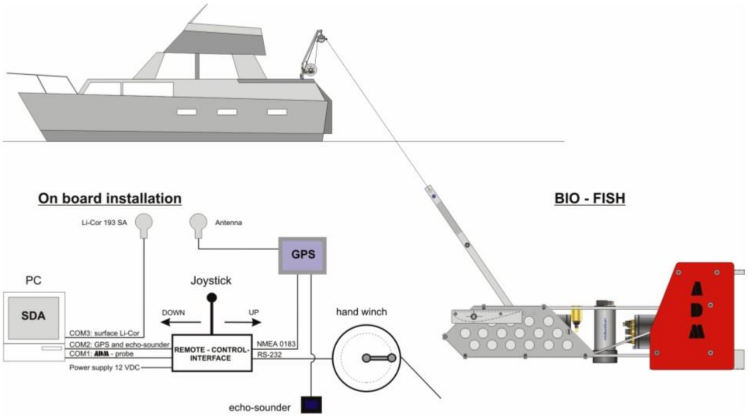

Figure 3. Illustration of Bio-Fish set-up. The size of the boat has been scaled down approximately 10-fold compared with the Bio-Fish device and on-board installation.

Water samples – nutrients and chlorophyll

BoPRC conducts routine (approximately monthly) water quality samples comprising water column profiles using a Sea-Bird CTD instrument, and water samples for analysis of dissolved and total nutrients and chlorophyll *a*. In Rotoehu, water samples were collected monthly at depths of 0-9 m (integrated tube sample) and 8-9 m (grab sample). Results presented in this report are for the period July 2009 to June 2013.

Chlorophyll and Secchi disk depth

UoW collected samples for analysis of chlorophyll *a* from the surface (0.5 m) and bottom (9 m) at two sites in Lake Rotoehu from December 2011 to June 2013. Water clarity was measured using a Secchi disk comprising a 20 cm diameter disk with black and white markings which is lowered into the water until no longer visible. UoW Secchi measurements were combined with the historical record of Secchi measurements by BoPRC, and each Secchi measurement was multiplied by 2.25 to estimate the euphotic zone–the depth corresponding to 1% of surface photosynthetically active irradiance.

Results

Meteorological data

Weather is the main driver of lake stratification, and can be a confounding variable in a multi-year study. Notably, 2011-2012 was an unusually cold and wet year while 2012-2013 was hot and dry (Figure 7).

Monitoring buoy – fixed sensors

Data from the monitoring buoy clearly show fluctuations in water temperature, with strong stratification events during the 2011-2012, and 2012-2013 summers, but also smaller events occurring as early as August (Figure 4). In December 2012 and January 2013 temperatures were much warmer than the previous summer, and there were several sustained periods of strong stratification (Figure 4). During these events, dissolved oxygen levels in the hypolimnion reached minima of close to 10% saturation (Figure 5). The Schmidt stability index, calculated in part from the temperature profiles, confirmed that stratification was generally stronger and more sustained in 2012/13 than in 20011/12 (Figure 6).

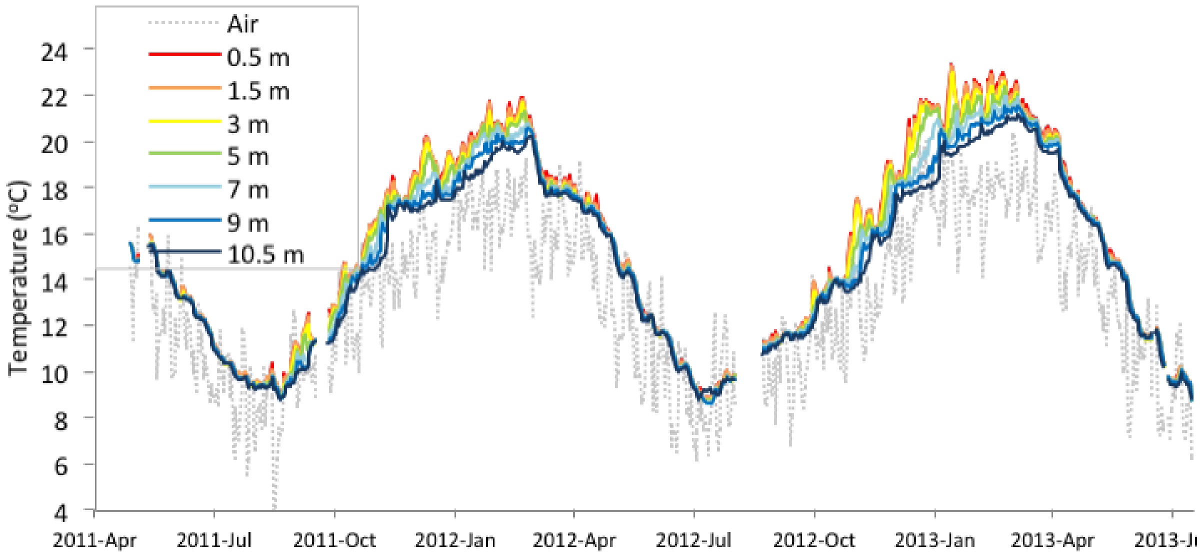

Figure 4. Temperature of air and water at different depths based on records from the monitoring buoy for the period April 2011 and July 2013. Sections of data have been corrected to account for drift of the buoy using B3 quality assurance/quality control software specific for this purpose.

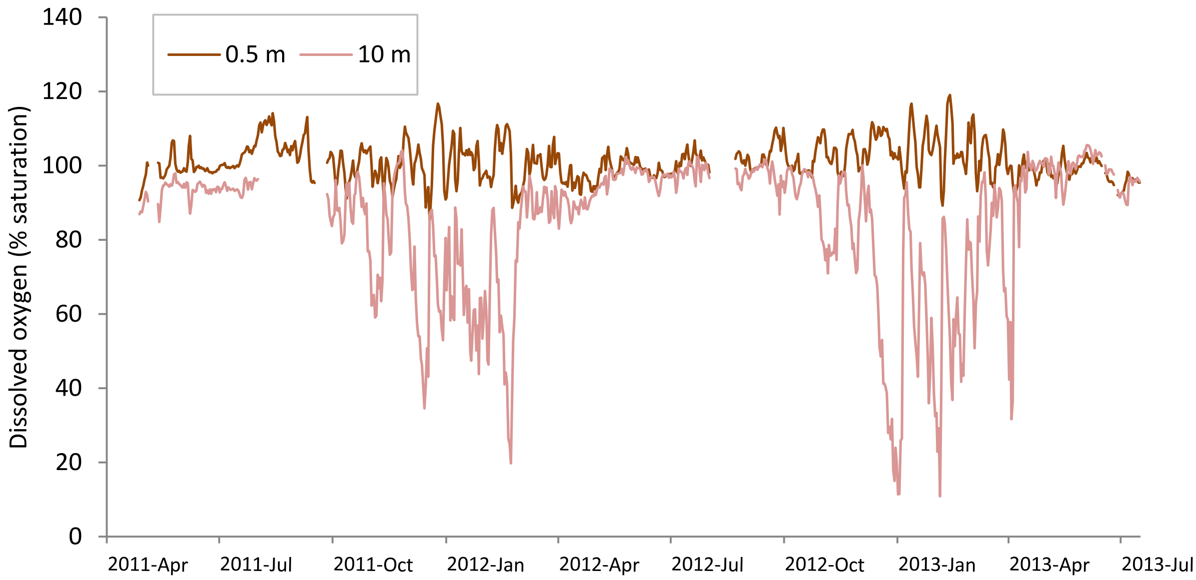

Figure 5. Percent saturation of dissolved oxygen at different depths, based on records from the monitoring buoy for the period April 2011 and July 2013. Sections of data have been corrected for electronic sensor drift.

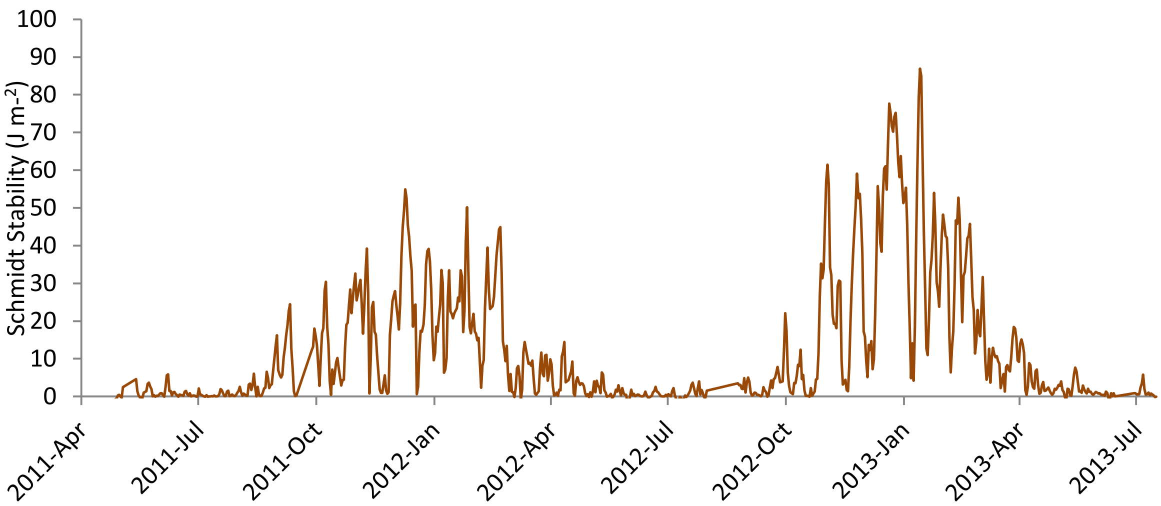

Figure 6. Schmidt stability index of Lake Rotoehu, based on records from the monitoring buoy for the period April 2011 and July 2013. Sections of data have been corrected to account for drift of the buoy. A high Schmidt stability value indicates stratification of the water column.

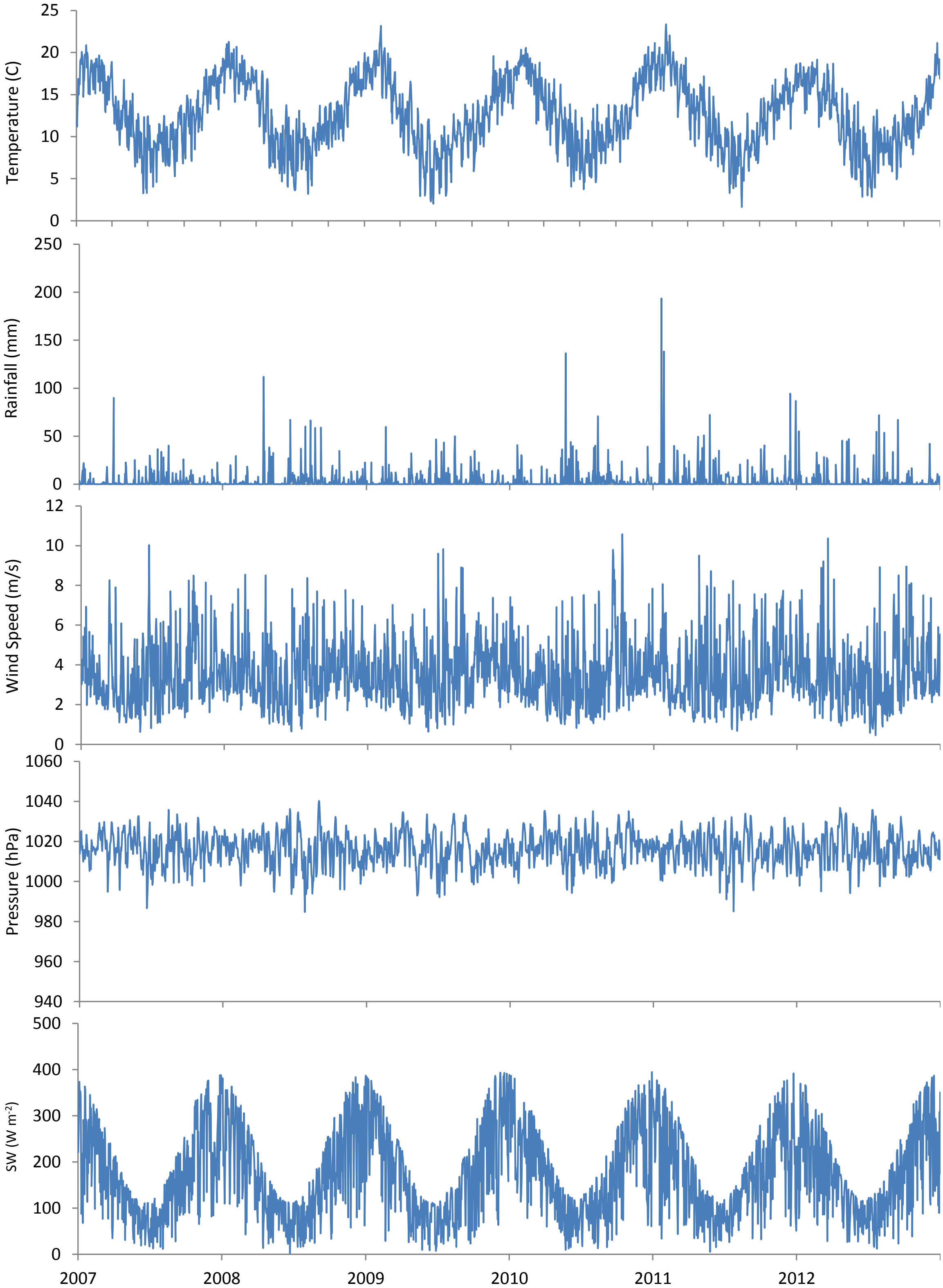

Figure 7. Meteorological data from January 2007 to December 2012, including short wave radiation (SW), air temperature, vapour pressure, wind speed, and rainfall. Data were obtained from the Rotorua Airport climate station with daily means calculated from hourly measurements.

Profiler Buoy

The UoW prototype profiler buoy was installed in the lake on 14 June 2013. In June and July the lake was generally well mixed and stratification was transient (Figure 8). A short period of multi-day stratification was observed in early July, however, and this was associated with some oxygen depletion in the bottom waters (Figure 9). Chlorophyll fluorescence was mostly uniformly distributed through the water column, with increasing concentrations in July (Figure 10). The pattern of chlorophyll fluorescence is consistent with expectations for Rotoehu during winter months, and will provide a baseline with the profiler buoy remaining in place over the summer of 2013/14.

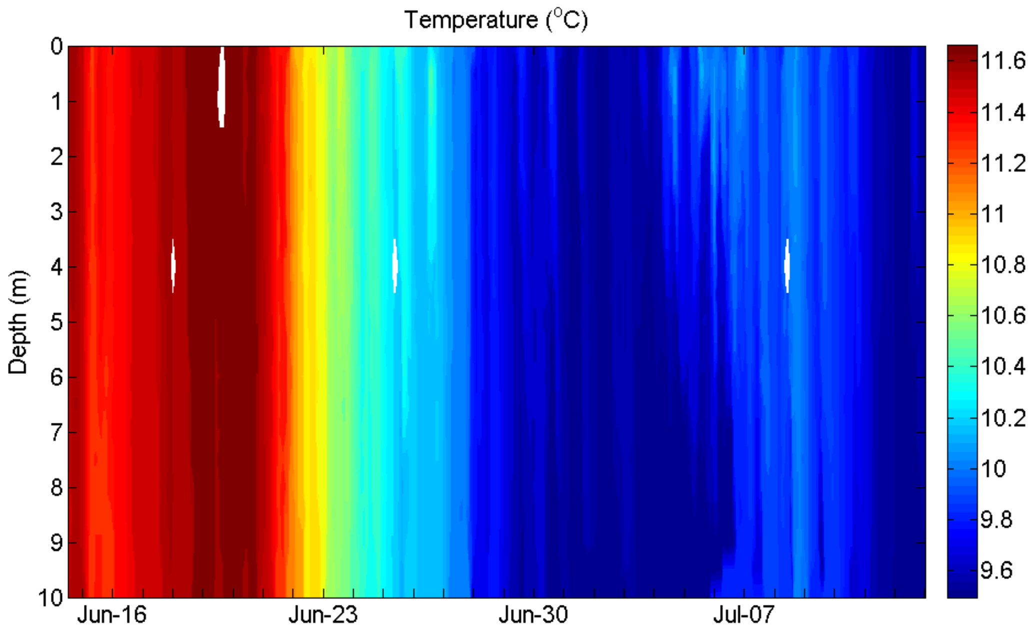

Figure 8. Water temperature at different depths in Lake Rotoehu as measured by the profiler buoy between June 14, 2013 and July 13, 2013. Areas of white represent insufficient resolution to allow interpolation of temperature.

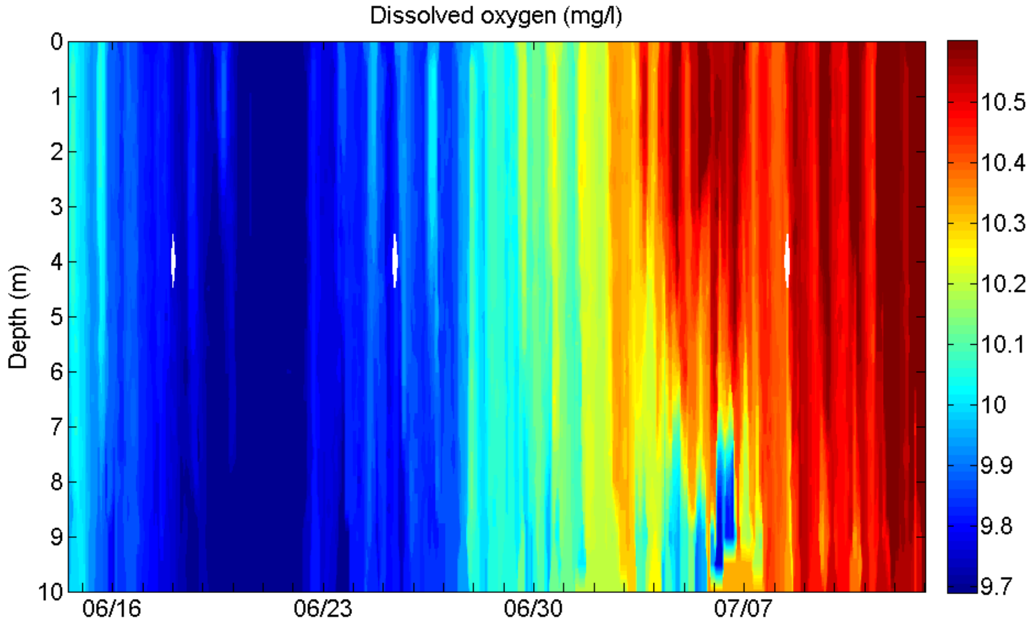

Figure 9. Dissolved oxygen concentration at different depths in Lake Rotoehu as measured by the profiler buoy between June 14, 2013 and July 13, 2013. Areas of white represent insufficient resolution to allow interpolation of dissolved oxygen.

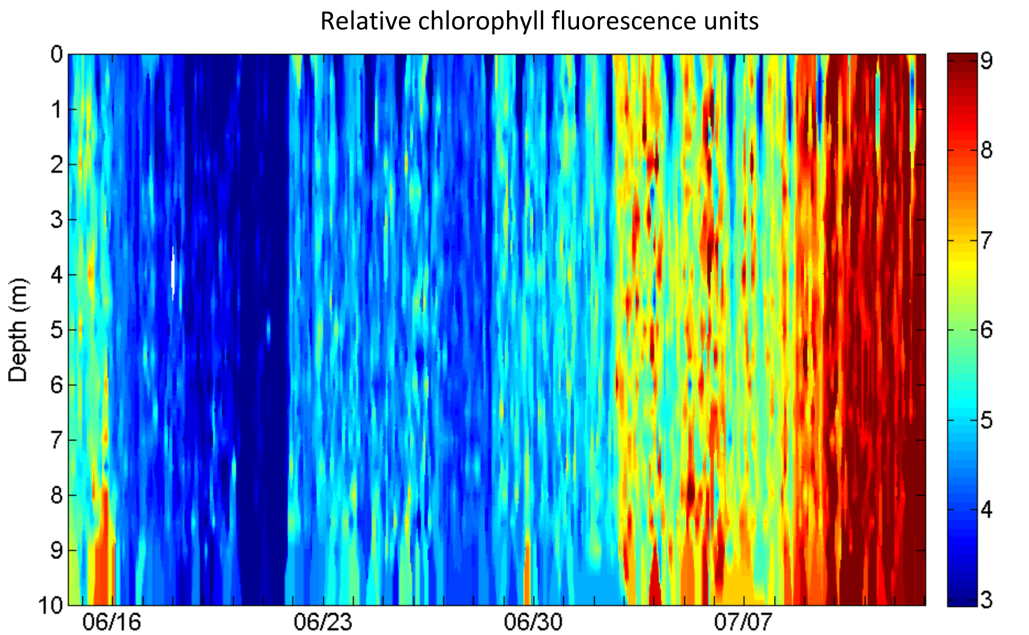

Figure 10. Chlorophyll fluorescence at different depths in Lake Rotoehu as measured by the profiler buoy between June 14, 2013 and July 13, 2013. Areas of white represent insufficient resolution to allow interpolation of fluorescence.

CTD profiles

CTD water column profiles were taken at two sites in Lake Rotoehu on 22 occasions between December 2011 and June 2013. Casts from Site A were collected adjacent to the southern aerator, and those from site B were located c. 400 m from the southern aerator (Figure 2).

Prior to installation of the mixing devices, water temperature profiles at the two sites were very similar on all sampling occasions, with the possible exception of 21 August 2012, when a weak thermocline at site B was not observed at site A (Figure 12). On many occasions following commissioning of the aerators, the water column was well mixed throughout the lake, precluding detection of effects by the aerator. However, on several occasions when there was some stratification, the water column near the aerator was more deeply mixed than that at site B, specifically 29 Nov 2012, 17 Jan 2013, and 22 February 2013 (Figure 12, Figure 13). These observations suggest that the aerators were capable of influencing the strength of stratification in the immediate area, although the effects were reduced rapidly with distance from the machine.

Bio-Fish

The Rotoehu BioFish transect (Figure 2) was surveyed on twenty occasions between 18 November 2011 and 21 March 2013. A large amount of data was generated from these transects and only selected examples are presented here. Generally, on transect samplings Rotoehu was mixed and the hypolimnion oxygenated (**Error! Reference source not found.**). During the summer, however, the lake was surveyed whilst stratified, and bottom conditions hypoxic (**Error! Reference source not found.**). The lake was again fully mixed in March of 2013 *(**Error! Reference source not found.**)*. These spatial surveys demonstrate important features in horizontal variability through the lake, such as the tilted of the thermocline observed on 22 February 2013 (**Error! Reference source not found.**). This highlights the importance of quantifying horizontal variability in water column structure in order to distinguish effects of destratification devices from natural phenomena such as seiches and internal waves. Also notable is the frequent disconnect between the very small northern basin and the main lake. The northern basin was frequently more stratified with higher water clarity, suggesting it may be fed by groundwater sources.

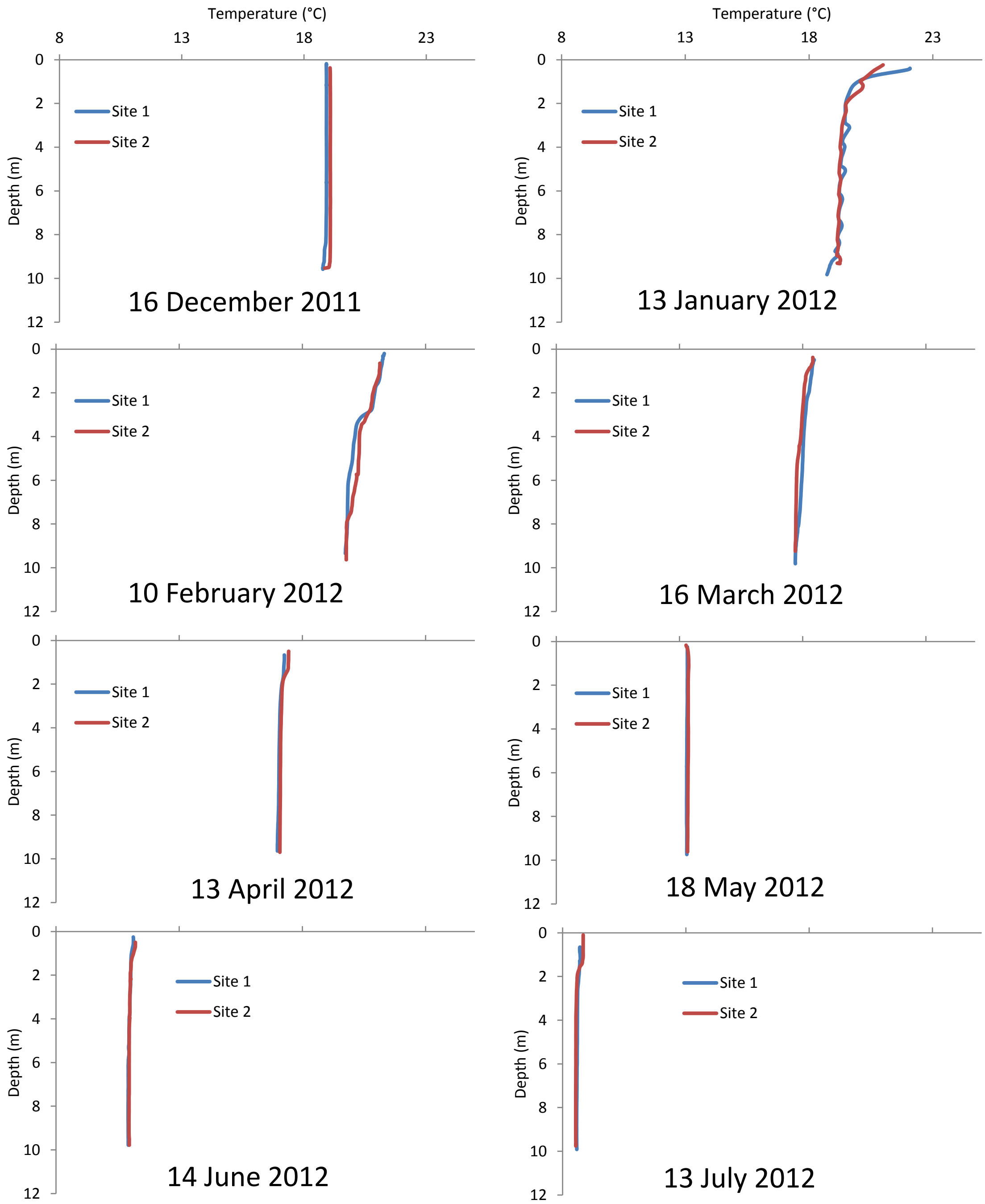

Figure 11. Comparison of CTD casts taken at site A (aerator location) and site B (c. 400 m from aerator). Casts presented are prior to installation of the aerators.

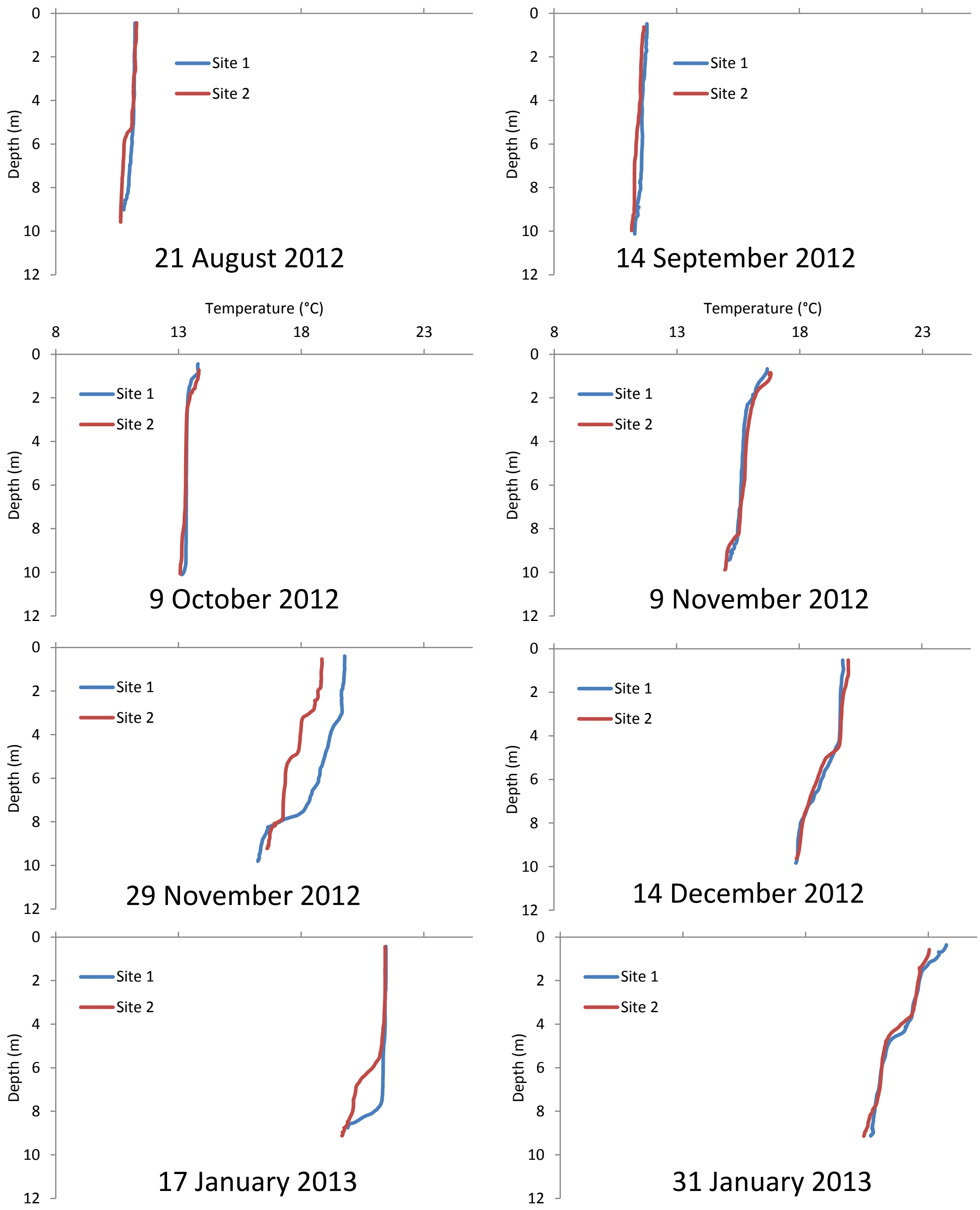

Figure 12. Comparison of CTD casts taken at site A (aerator location) and site B (c. 400 m from aerator). The aerators were active from November 2012.

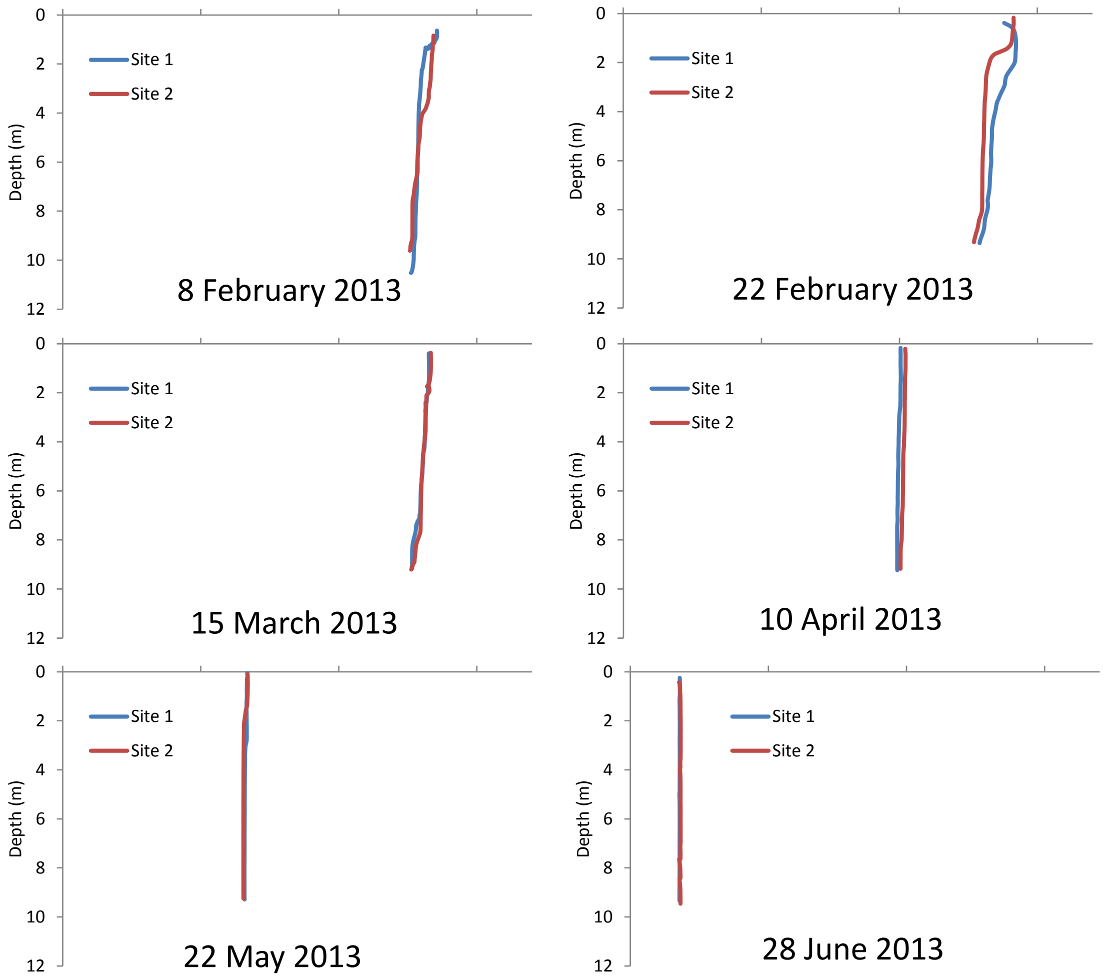

Figure 13. Comparison of CTD casts taken at site A (aerator location) and site B (c. 400 m from aerator). Casts presented are following the installation of the aerators in November 2012.

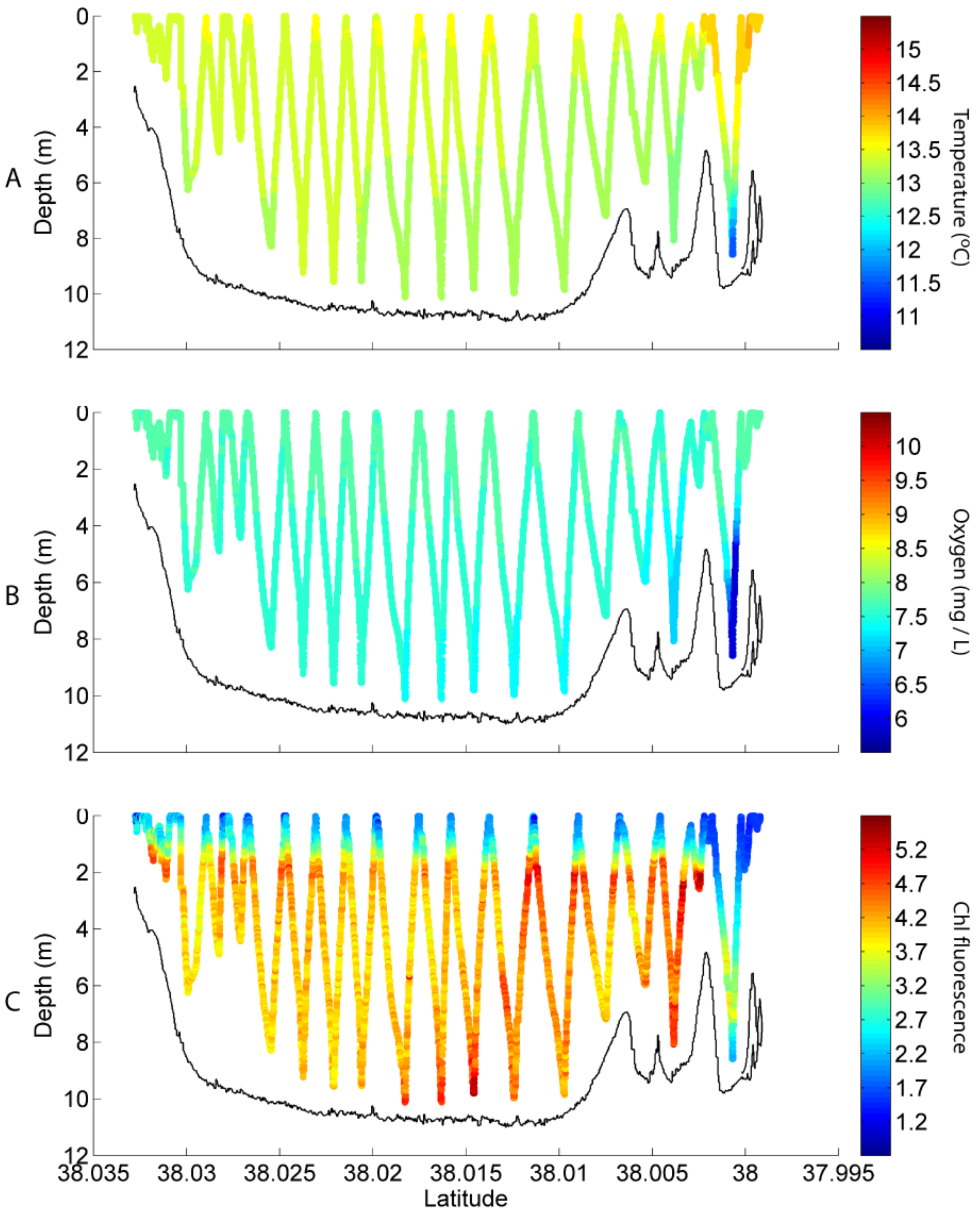

Figure 14. Cross-section of Lake Rotoehu showing the undulating path of the Bio-Fish device through the water on 9 October 2012 for A) water temperature, B) dissolved oxygen concentration, and C) chlorophyll fluorescence. Fluorescence data are reduced near the water surface, likely indicating non-photochemical quenching (bright-light inhibition).

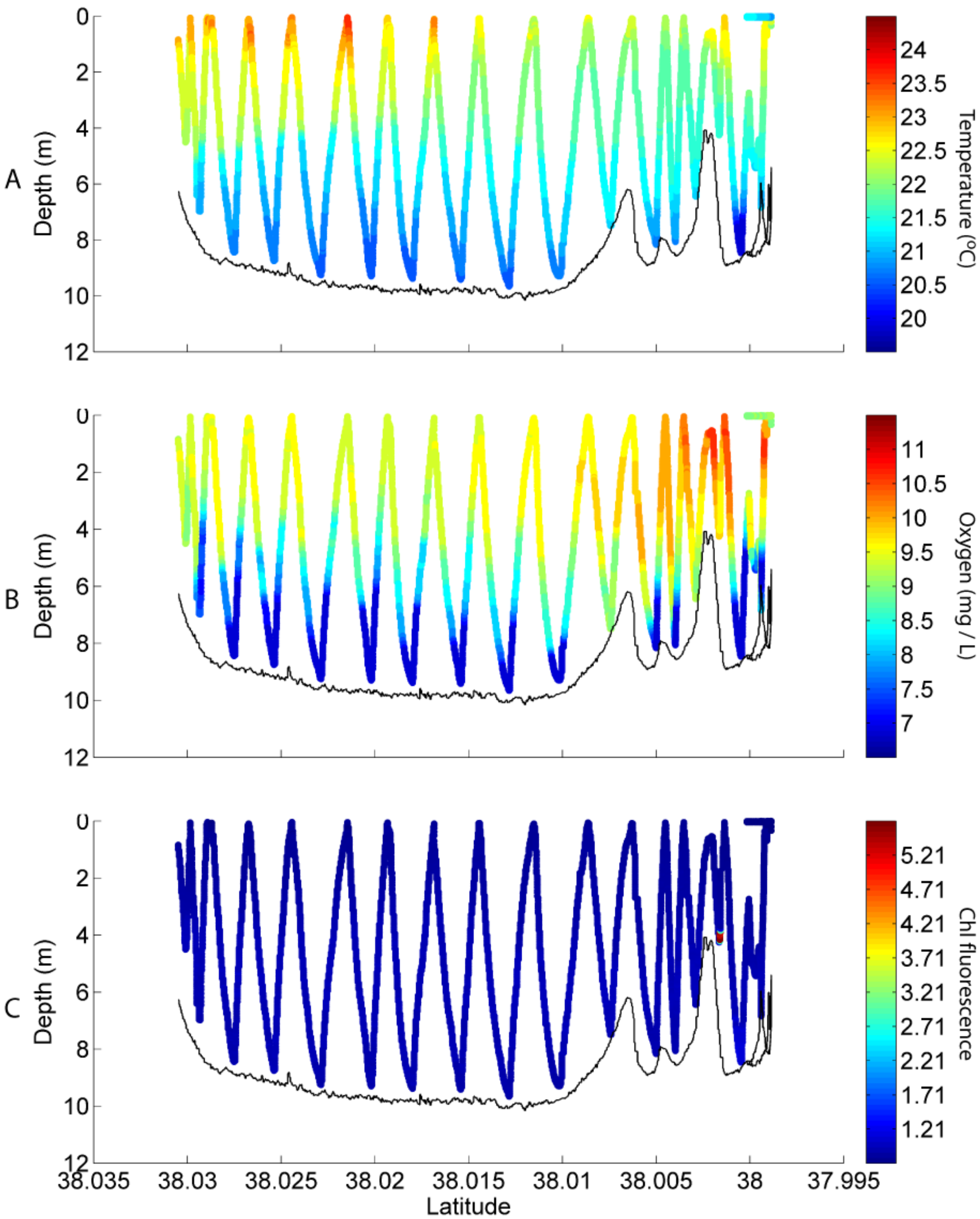

Figure 15. Cross-section of Lake Rotoehu showing the undulating path of the Bio-Fish device through the water on 31 January 2013 for A) water temperature, B) dissolved oxygen concentration, and C) chlorophyll fluorescence.

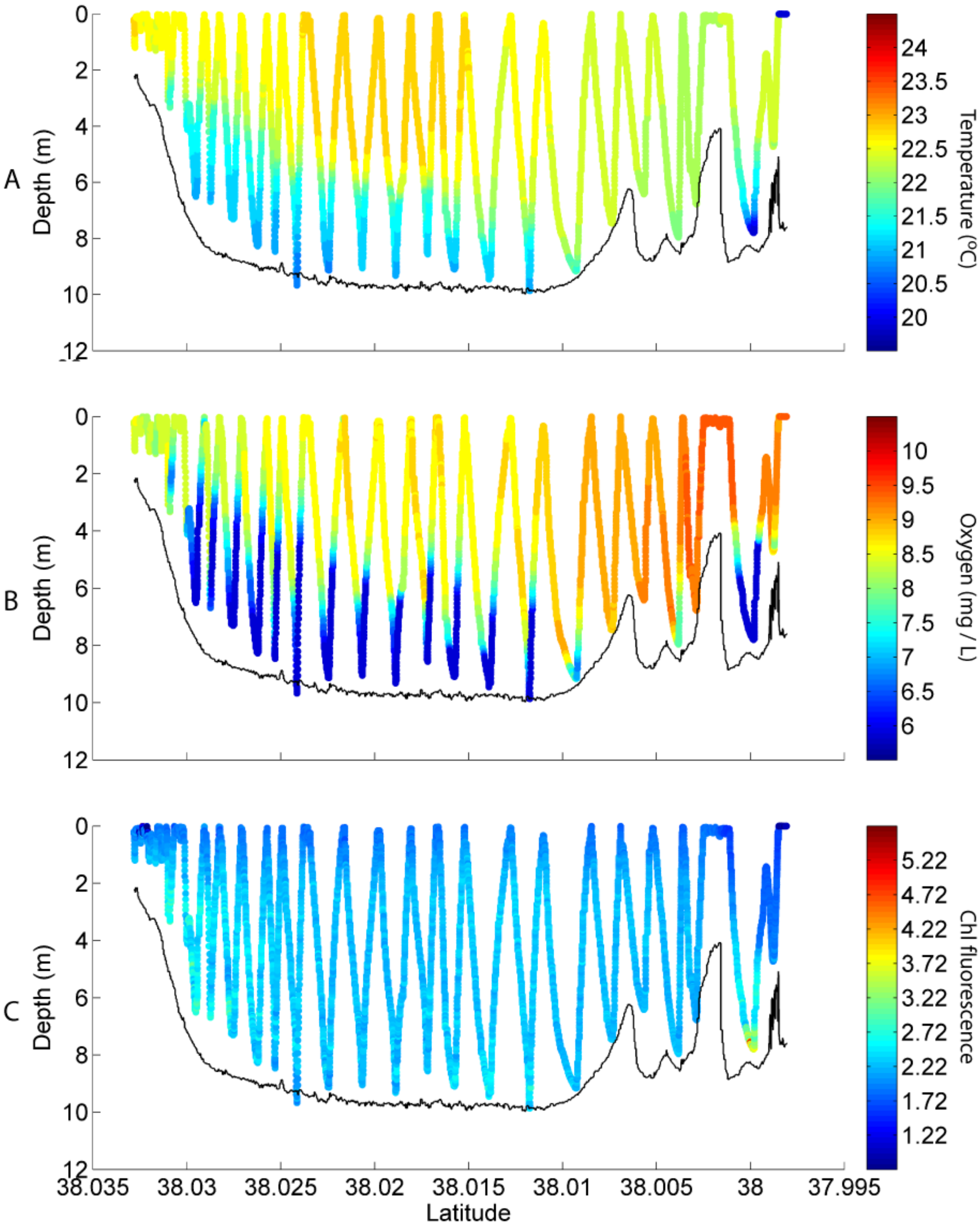

Figure 16. Cross section of Lake Rotoehu showing the undulating path of the Bio-Fish device through the water on 22 February 2013 for A) water temperature, B) dissolved oxygen concentration, and C) chlorophyll fluorescence. The lake was strongly stratified with evidence of oxygen depletion in bottom waters. Note uneven depth of stratification across the transect.

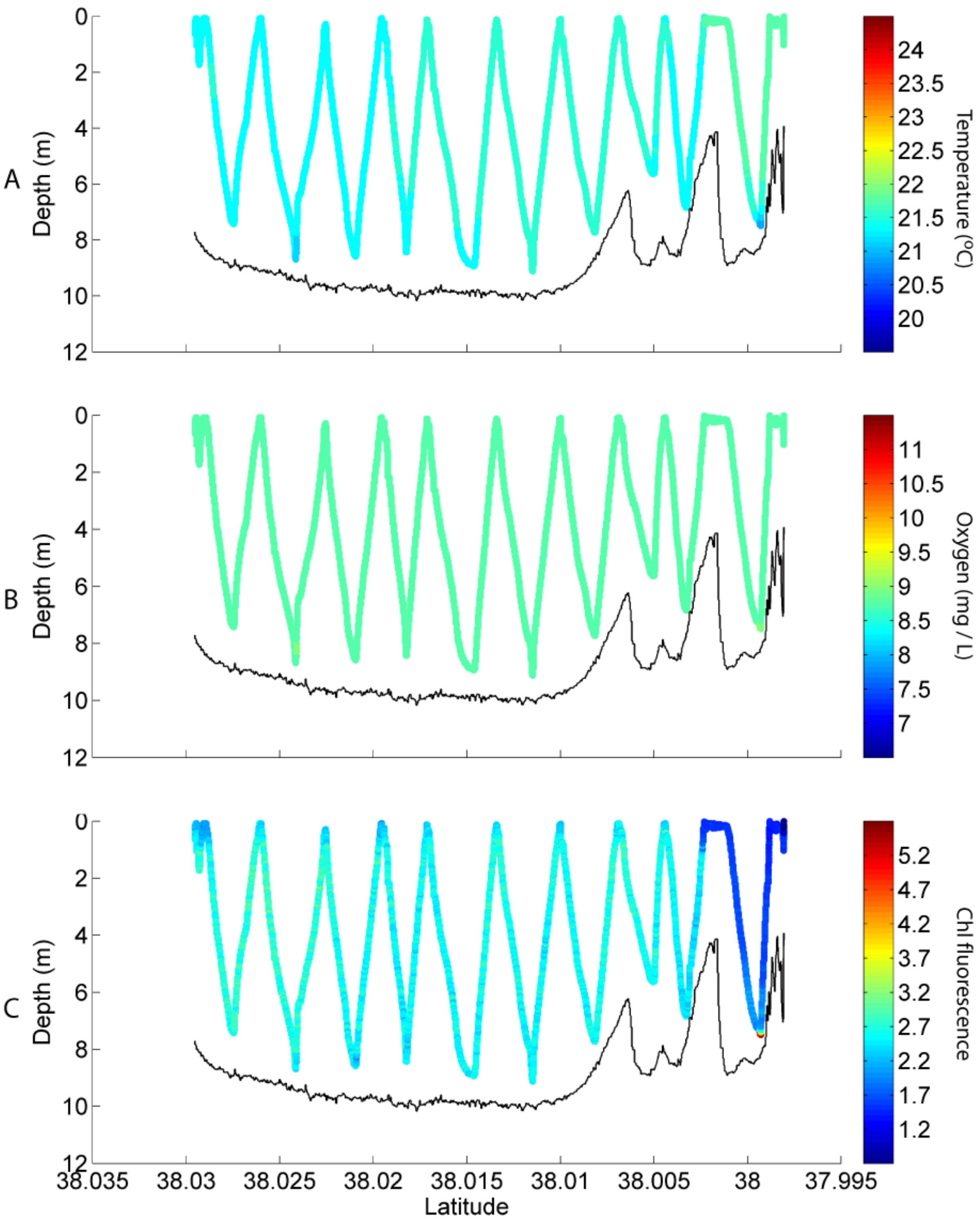

Figure 17. Cross-section of Lake Rotoehu showing the undulating path of the Bio-Fish device through the water on 01 March 2013 for A) water temperature, B) dissolved oxygen concentration and C) chlorophyll fluorescence.

Long term monitoring

Nutrient analysis (source: BoPRC) showed a general trend of reduction in total nitrogen and total phosphorous in Lake Rotoehu, for both the epilimnion and hypolimnion.

No clear pattern was evident in the temporal pattern of total nitrogen concentrations in the lake (Figure 18). Inorganic nitrogen generally represented only a small fraction of total nitrogen in surface and bottom waters, with relatively elevated levels of both nitrate and ammonium observed in surface and bottom waters on a few occasions. By contrast, inorganic phosphorus (phosphate) comprised a larger proportion of total phosphorus. Distinct summer peaks in phosphorus were observed in 2009/10 and 2010/11, however, this pattern was much weaker in subsequent summers (Figure 19).

Observed improvements of in-lake nutrient concentrations may be driven to some extent by efforts to improve land management practices, alum treatment of the geothermal Soda Spring inflow, and/or removal of weeds from the lake.

The relatively high concentrations of inorganic P to inorganic N at certain times may explain the sporadic proliferation of cyanobacteria, of which many species are able to meet shortcomings in supply of inorganic N by fixing atmospheric N during stratification. A reduction in turbulent mixing and buoyancy properties can increase their capacity to aggregate in near-surface waters.

Lake level monitoring data (BoPRC) showed significant fluctuations in Rotoehu, with a nearly 2 m range between 2009 and 2013. Over 2011 the lake level increased by more than 1 m, with a subsequent rapid fall in level following October 2012 (Figure 20). The effect of water level should not be overlooked when considering the thermal regime of the lake, because energy required to mix the water column will generally be higher when lake level is high. Secchi depth appeared to follow a somewhat similar pattern to water level, however this was not true of 2012, when Secchi depths were relatively low.

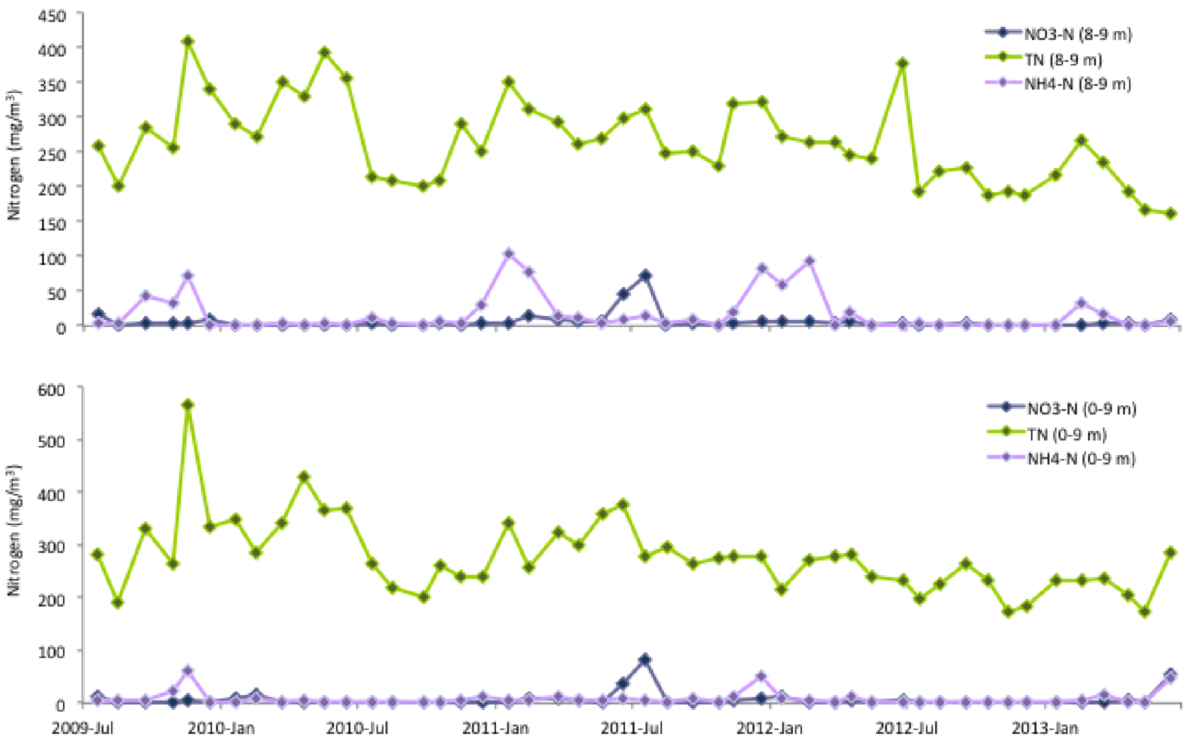

Figure 18. Concentration of nitrate (NO_3), ammonium (NH_4) and total nitrogen in Lake Rotoehu for A) integrated water samples (depths from 0-9 m), and B) deep water samples (8 9 m), from July 2009 to July 2013.

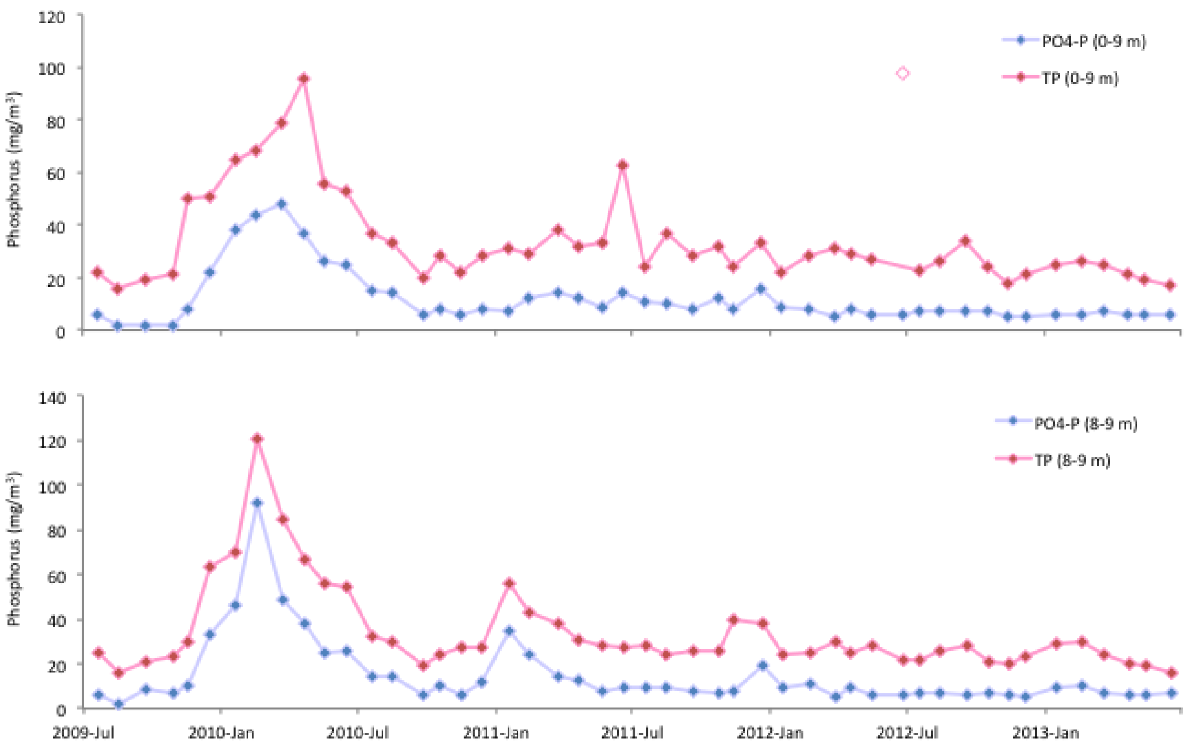

Figure 19. Concentration of phosphate (PO_4) and total phosphorous in Lake Rotoehu for A) integrated water samples (depths from 0-9 m), and B) deep water samples (8-9 m). Time series data from July 2009 to July 2013. Outlined TP data point in June 2012 is assumed to be erroneous and is excluded from analysis.

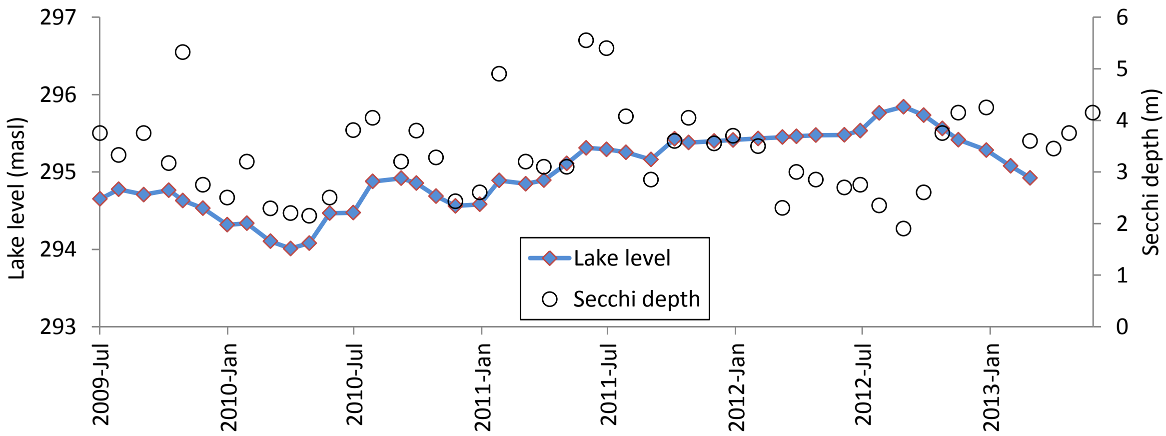

Figure 20. Surface water level and Secchi depth of Lake Rotoehu from Jul-2009 to Mar-2013 (Source: BoPRC).

The euphotic zone in Lake Rotoehu has historically been 10 m or deeper, indicating sufficient light for photosynthesis through the entire water column. This was frequently observed in measurements before 1993 (Figure 21). Between 1993 and 2004 Rotoehu water clarity was severely reduced. Since 2004, Secchi depth has been highly variable, likely in part due to phytoplankton blooms. Occasional instances of high clarity have been recorded over recent years (Figure 21), possibly as a result of previous efforts to manage nutrient losses from the catchment and in-lake restoration actions. During 2012, clarity was fairly stable, with a notable increase in clarity in November. However, by February, clarity had returned to levels observed in 2012, with higher frequency monitoring elucidating much variability at a sub-monthly time scale.

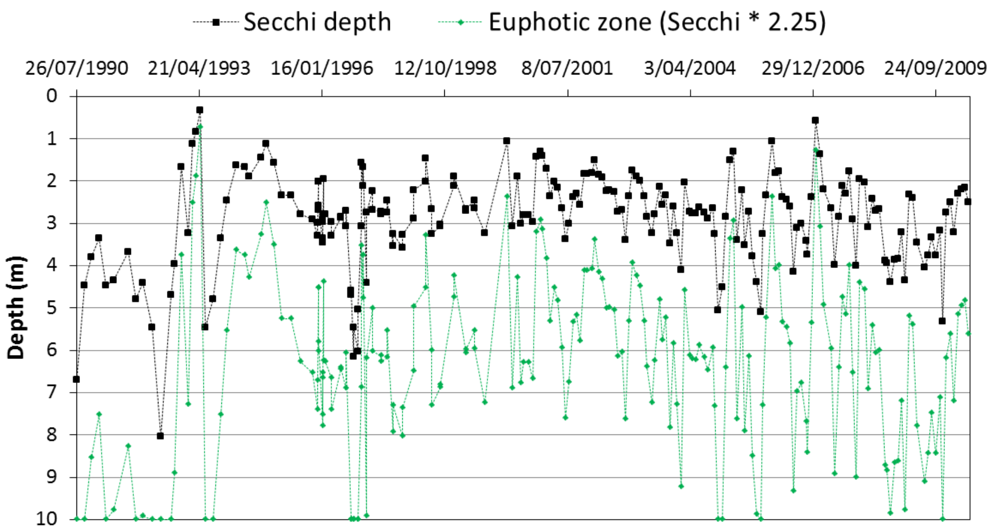

Figure 21. Historical Secchi depth and corresponding estimates of euphotic zone depth (Secchi depth * 2.25) from 1990 to 2009.

Chlorophyll *a* grab samples showed some evidence of a decrease over the four-year period (Figure 24), although concentrations were relatively high in winter 2012. Notably, summer chlorophyll concentrations in 2012 and 2013 were low relative to the winter maxima in these years. Winter chlorophyll maxima, usually driven by abundance of diatoms, are typically indicative of healthy lake ecosystem function (Ryan et al. 2006).

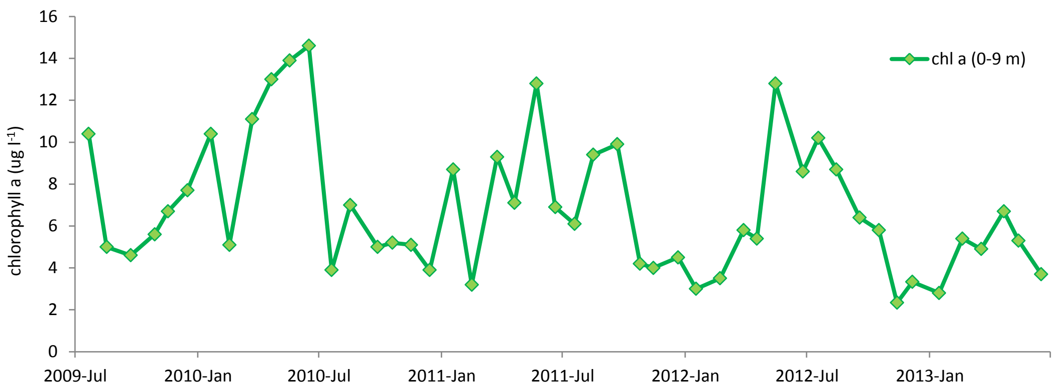

Figure 22. Chlorophyll a monitoring data from BoPRC, 2009 to 2013.

Chlorophyll comparison between sites

Chlorophyll *a* followed a similar pattern at sites A and B over the monitoring period and in near-surface ("epilimnion") and deep-water ("hypolimnion") samples. At both sites concentrations peaked in August 2012, and were highly variable during the summer of 2013 (Figure 23, Figure 24). It is notable that despite the observed increased intensity and duration of stratification in summer 2012/13, chlorophyll *a* concentrations were relatively low compared with the previous, more weakly stratified summer.

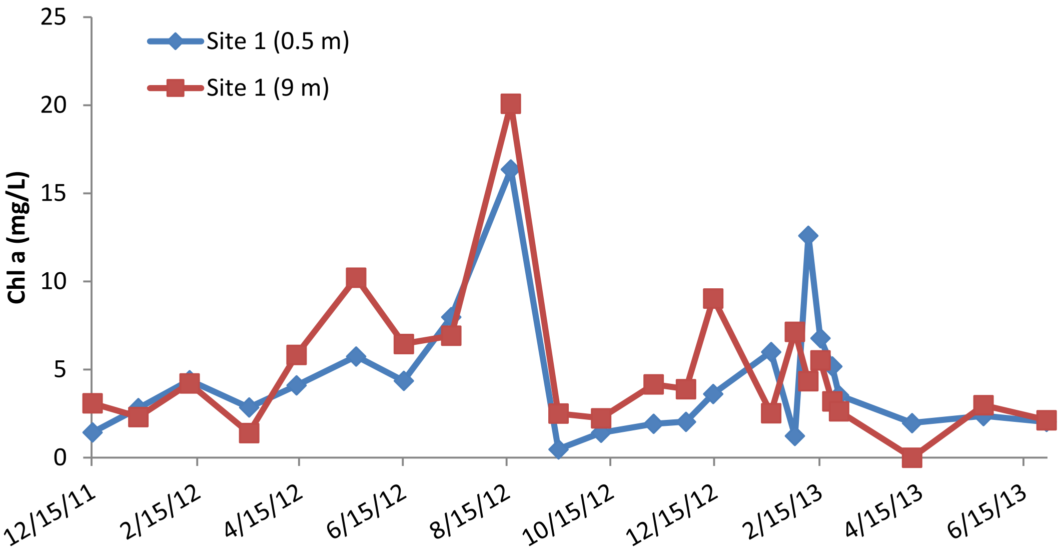

Figure 23. Chlorophyll *a* at site 1 in the hypolimnion and epilimnion between December 15 2011 and June 28 2012.

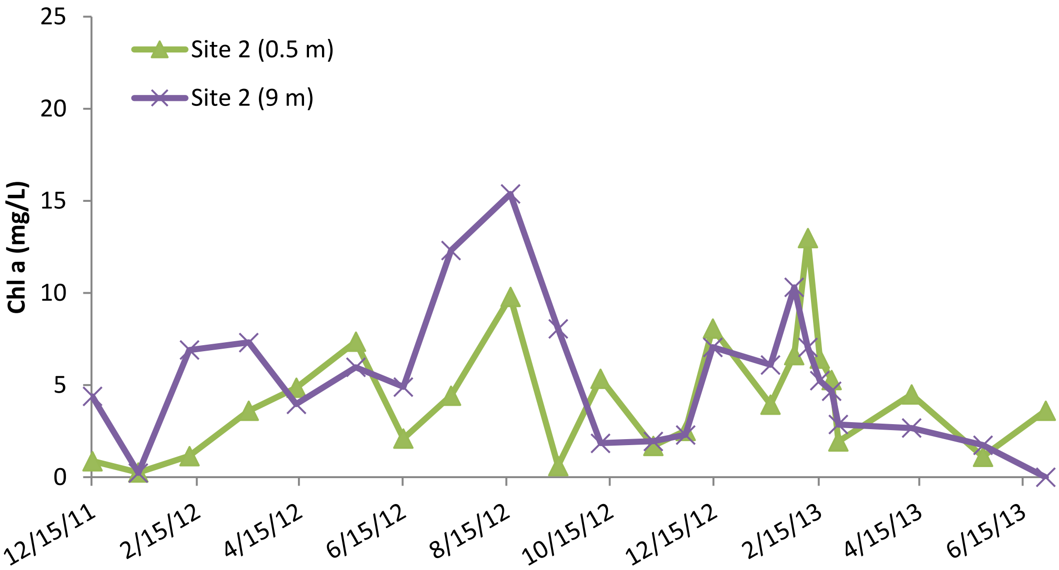

Figure 24. Chlorophyll *a* at site 2 in the hypolimnion and epilimnion between December 15 2011 and June 28 2012

Discussion

A multi-faceted monitoring approach has provided considerable insight into the effects of deployment of two artificial water column mixing devices on Lake Rotoehu from November 2012 to June 2013. Water column profiles show that the present mixing devices are capable of modifying the thermal structure of the water column in the immediate vicinity of a machine; however, concurrent monitoring just hundreds of meters away showed that these effects were rapidly reduced with horizontal distance from the device.

Several factors specific to Lake Rotoehu may have reduced the efficiency of the devices. Macrophytes, principally hornwort, are abundant in Rotoehu and frequently form large floating 'rafts' of weed. These were observed to regularly foul the intake of the devices, thus reducing effective flow rates. Aquatic plants may also further reduce the effectiveness of the devices by disrupting horizontal flow near the lake bottom, and interfering with horizontal dispersion near the surface.

Dense, cold water from the hypolimnion may not mix well with warm surface water, but sink rapidly back to the bottom, to be re-entrained by the mixing device. This could explain the localised effects on the lake thermal structure observed during monitoring. Refinement of the device moorings, air flow rates, and protection from weed fouling might reduce the sinking effect and improve horizontal dispersion. The relatively shallow water column in Rotoehu may provide insufficient duration for entrained hypolimnetic water to become air-saturated, and thus result in less aeration than may occur in deeper systems.

The observed level of efficacy of destratification is consistent with predictions from mathematical modelling carried out by UoW before the deployment of the devices in Rotoehu (unpublished data). Although improving flow rates of the existing destratifiers could increase the horizontal extent of their impact, Rotoehu is relatively large (c. 8 km^2) compared with other lakes and reservoirs where artificial destratification has been successful. The lake receives an enormous input of solar energy, and modelling suggests that many additional devices would be required to modify mixing in the lake to an extent that would impact water quality on a wider scale.

That being said, data presented here encompass only a single summer/autumn of mixing device activity. Summer of 2012/13 was unusually hot and dry, therefore lake stratification was particularly strong and artificial lake mixing would have required greater energy input than typical summers. By contrast, summer 2011/12 (the 'baseline' period) was unusually cold and wet (Figure 7). Additional years of monitoring might be beneficial for better evaluating the efficacy of the artificial mixing devices.

Nutrient, chlorophyll and clarity monitoring data 2009 – 2013 reveal promising trends in water quality. It should be considered that because Rotoehu may stratify and mix at time scales of weeks rather than seasons, the present water sample record may not represent all periods of nutrient release and phytoplankton proliferation. Nevertheless, recent trends in total and inorganic nutrients, particularly phosphorus, in Rotoehu are compelling. Total nitrogen and, particularly, total phosphorus were greatly reduced in 2011-2013 relative to 2009-2011. Recent seasonal chlorophyll patterns are characterised by maxima during winter, when the water column was usually mixed, rather than during the stratified summer period. Despite atypically strong stratification in summer 2012-13, major cyanobacterial blooms were not observed. These are generally characteristics of 'healthy' New Zealand lake ecosystems (Ryan et al. 2006).

Although more thorough water column mixing has the potential to reduce the severity and aesthetic impact of cyanobacteria blooms, these results highlight the importance of managing nutrients to control the occurrence of algae blooms in Rotoehu. Specifically, the observed restriction of the supply of inorganic phosphorus during stratified periods over the most recent summers coincides with reduced summer phytoplankton concentrations. Although N-fixing cyanobacteria are capable of meeting shortfalls in nitrogen supply, phosphorus supply cannot be circumvented. Further work could be aimed at quantifying the drivers of the observed reduction in nutrients, i.e. the relative contributions of atmospheric conditions, land management, and the action of P-binding in inflows and/or sediments via inflow dosing with alum. These aspects are likely to have important implications for the management of Lake Rotoehu.

Conclusions

Monitoring data have shown that the current artificial mixing devices are capable of modifying the local water column structure to a moderate extent. Although refinement of these installations could improve their performance, it is likely that the existing machines are incapable of effecting significant thermal change on a basin-wide scale. This conclusion has been corroborated both by monitoring over recent years, and by ecosystem modelling. Deployment of mixing devices in Rotoehu has provided a valuable indication of the scale of application required to effectively mix medium to large lakes.

In the context of recent water quality monitoring it appears that external load reduction is both achievable and highly promising for the control of summer phytoplankton blooms and trophic state in Lake Rotoehu. Despite strong and sustained periods of stratification accompanied by relatively greater dissolved oxygen depletion in bottom waters over summer 2012/13, summer chlorophyll concentrations were generally low over this period compared with previous years. This suggests that external load may be relatively more important than internal load and/or stratification patterns in driving phytoplankton blooms on the lake. Therefore, Lake Rotoehu restoration efforts may be more effective if targeted towards external load reduction rather than modification of the thermal structure of the lake.

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