A TELEMETRIC MONITORING SYSTEM FOR ESTUARINE ALGAL BLOOM MANAGEMENT

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Abstract

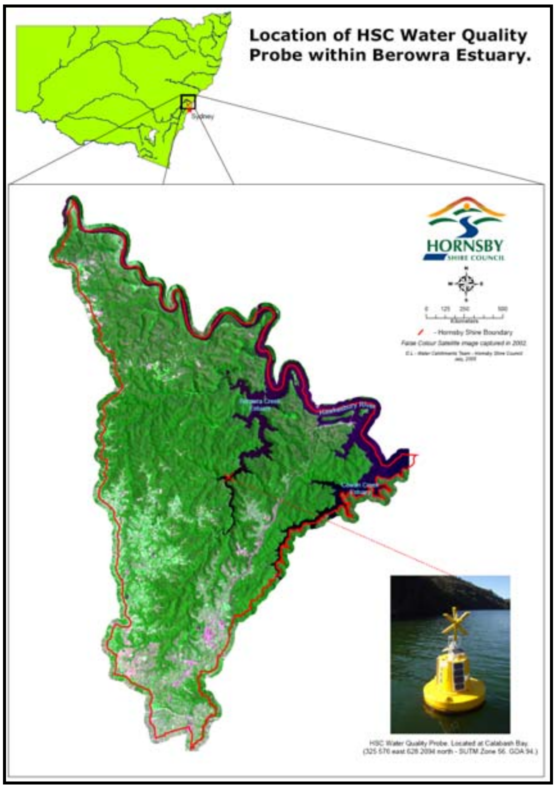
Algal blooms are problematic for estuarine areas and are often associated with discoloration of marine water, depletion of oxygen, fishkills and potential shellfish poisoning. Globally, Harmful Algal Blooms (HABs) have become more frequent, more extensive and more severe (Hallegraeff, 1993, Anderson, 1994). Current approaches to algal bloom management are informed by principally reactive sampling methods, whereby information is collected and reported to environmental managers with a lag time which is dependent upon field collection, laboratory analysis and reporting time. This paper presents a monitoring system that supports a proactive management regime for the management of estuarine algal blooms. This monitoring system utilises in situ data collection technology and telemetry to provide managers of estuarine systems with a novel approach to bloom management. Further, by employing such a system greater understanding of the causality and dynamics of algal blooms is achieved, by monitoring environmental conditions and phytoplankton response to these conditions before, during and after a bloom.

Introduction

Problematic algae and subsequent algal blooms are prevalent within the Lower Hawkesbury Estuary (Haines et al., 2008). Problematic algae within the Berowra estuary predominately occur from the divisions of *Ochrophyta* (Diatoms), *Dinophyta* (Dinoflagellates), *Cryptophyta* (Cryptophytes), *Chlorophyta* (Green algae). Algal blooms alter the ecosystem in which they occur and can cause fish mortalities and have detrimental implications for human health and socio-economic activities such as tourism and aquaculture (anZingone and Oksfeldt Enevoldsen, 2000). Generally, algal blooms form when a favourable set of environmental conditions exist. Conditions considered to influence bloom conditions include nutrients, hydrological factors (such as flow, residence times, water column stability), solar radiation, temperature and species interactions.

To manage algal blooms within the Berowra estuary Hornsby Shire Council and Manly Hydraulics Laboratory have developed a telemetric monitoring system and associated procedure for managing and informing the response to algal blooms. The monitoring system has been deployed since 2002 above a 14m deep hole near Calabash Bay within the Berowra estuary, approximately 30km North of Sydney. This site was selected as previous estuary process studies indicate that typical bloom characteristics were shown to have peak Chlorophyll-a (Chl-a) concentrations within this area of the deep hole (MHL, 1998a).

Figure 1 Probe location within the Berowra Creek estuary



This paper provides an approach towards generating relevant data to manage algal blooms. The intent of this paper is to explain how relevant data is obtained to inform algal bloom management using a novel telemetric monitoring system. A rigorous understanding of algal ecology, factors contributing to bloom formation and die off and predictive capability, is currently being researched by Hornsby Shire Council. With an understanding of this monitoring system it is anticipated managers of estuaries will be provided with an option of undertaking a similar data generation exercise in order to manage problematic algal blooms within their areas of interest.

Methods

Coordination of probe deployment, verification and calibration has been principally undertaken by Manly Hydraulics Laboratory and Hornsby Shire Council. The probe instrumentation (YSI^{TM} 6820 sonde) for this project has been deployed primarily in its current location above a deep hole between Calabash Point and Cunio Point in since 2002.

Monitoring system development

The development of the monitoring system occurred over two stages. Stage-1 was a field trial to determine the effectiveness of the YSI^{TM} sonde as tool for measuring an approximation of the chlorophyll-a content and hence the concentration of algae (MHL, 2003). Specifically, stage-1 sought to investigate the correlation between fluorescence of the sonde and actual chlorophyll-a readings, monitor the amount of drift in the data during field deployment and develop an appropriate calibration procedure for the instrument. The results of stage-1 established that the fluorescence technique provided a good representation of actual chlorophyll-a concentrations and was therefore considered to be of sufficient accuracy to indicate the incidence of an algal bloom. With regard to establishing an appropriate calibration technique, it was considered that future probe deployments be made using only factory settings combined with field samples to determine a suitable relationship (MHL, 2003). The probe was changed every month, however, the data indicated that the probe could be deployed for longer periods, up to 3 months, as there was little drift in the data. To limit potential problems of fouling during deployment in the estuary, the probe has an automated wiper attached. The wiper completes a cleaning cycle of the probe optics prior to each measurement being taken to reduce the occurrence of marine fouling biasing results. Further, the probe sensors are encased in a perforated plastic housing to prevent damage from objects floating in the water. A copper mesh is then placed around the casing designed to prevent organisms from attaching and fouling the instrumentation. Routine cleaning and probe changes occur every 3 weeks which further reduces problems of fouling and vandalism.

The information gathered and protocols developed from stage-1 led to a further six-month trial (MHL, 2003) known as stage-2, which aimed at developing an appropriate site setup for deploying the instrumentation in Berowra Creek and to further monitor the amount of drift in the data during longer deployments in the field. Specifically, as part of stage-2 the hardware required for a telemetric system that is still in current use, was developed.

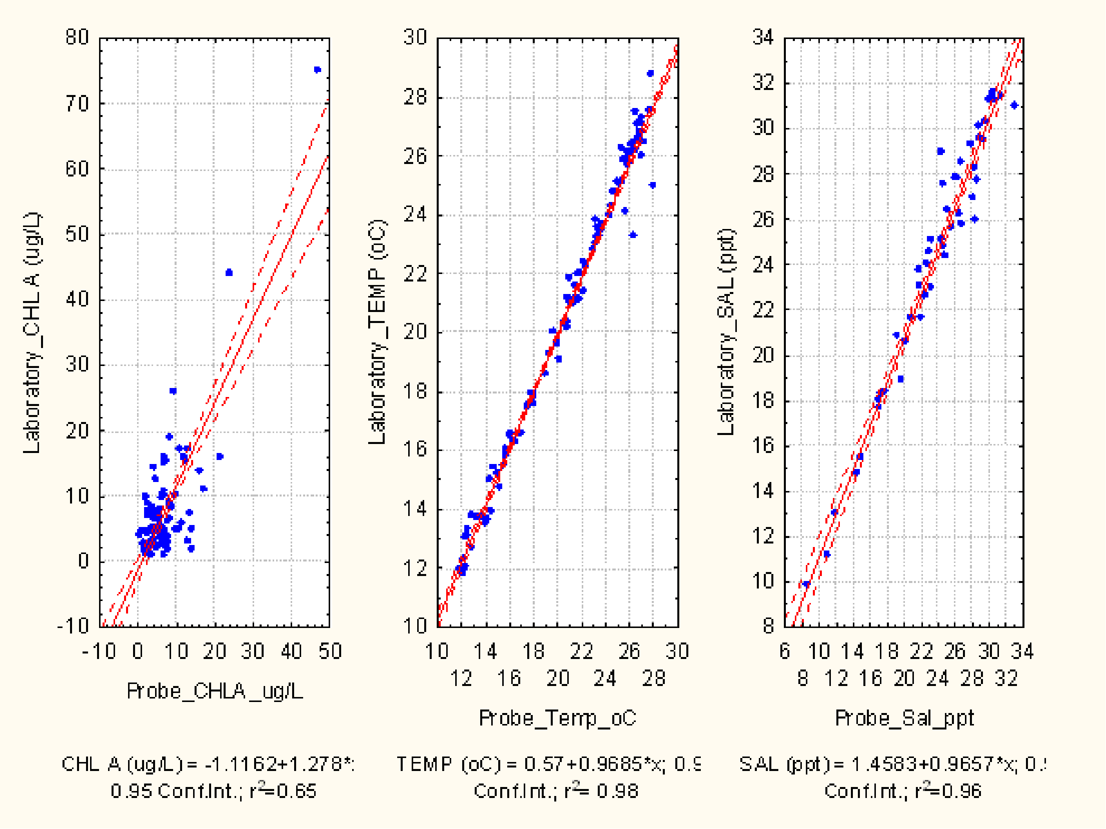
Current Deployment

The instrumentation is currently housed within a buoy to maintain the probes and associated equipment at the headwaters of Calabash Bay. Power to the probe and the telemetry system is provided by solar panels that are attached on the outside of the buoy encasement. The YSI^{TM} sonde is deployed at 0.5m depth and is connected to a data logger and mobile phone. Measurements are taken every 15 minutes and stored within an onsite data logger. This data is later downloaded via mobile phone each morning at 0600 hrs EST. The data is then available online to the public via the Hornsby Shire Council estuary management website (www.estuary.hornsby.nsw.gov.au).

Field Calibration

For calibration purposes water samples were collected by MHL from the site during the initial two stages of development. Samples were collected by MHL using a Niskin sampler triggered at 0.5 m depth adjacent to the buoy. Since the probes deployment in its current location at Calabash bay water samples have been collected monthly by HSC as part of an ongoing monitoring programme for chlorophyll-a and the algal species identification. Parameters measured as part of the routine monitoring include: chlorophyll-a, phytoplankton counts (total species composition and cell number), total phosphorous, soluble reactive phosphorus, total nitrogen, ammonia, oxidised nitrogen, suspended solids, faecal coliforms, pH, conductivity, salinity, turbidity, temperature and dissolved oxygen. Comparative results between the probe parameters and field data are shown in Figure 2.

Figure 2 Laboratory vs Probe instrument recordings



YSI^{TM} 6820 Sonde Parameters

Parameters monitored by the YSI^{TM} 6820 sonde include florescence/chlorophyll, salinity and temperature. Sensor specifications for the YSI^{TM} 6820 sonde are shown in Table 1 below. YSI^{TM} does not provide specifications for chlorophyll as it is recommended that field fluorescence readings be related to data from lab-analysed field samples.

Table 1 YSI 6820 Sonde Specifications

Parameter	**Measurement Range**	**Accuracy**	**Resolution**
Chlorophyll	0-400ug/L	No specifications provided	0.1 µg/L
Conductivity	0-100mS/cm	+/- 0.5% of reading + 0.001 mS/cm	0.001-0.1mS/cm
Temperature	-5 to + 45°C	0.15 °C	0.00 °C

Chlorophyll

Photosynthesis is the process by which plants, algae and some bacteria and protistans absorb solar energy to produce sugar, a form of energy that can be utilised by all organisms (Bell, 1992). The conversion of unusable sunlight energy into usable chemical energy is undertaken within the green pigment chlorophyll. Those organisms containing chlorophyll constitute the plant kingdom. Chlorophyll is a complex pigment, it is green in colour and absorbs light in the blue spectrum and to a smaller extent in the red region of the spectrum (Bell, 1992). A number of different forms are known (a,b,c,d,e) with each having a characteristic absorption spectrum.

Chlorophyll-a has been used as the central indicator for estuarine algal blooms. The concentration of Chlorophyll-a is considered to be a good indicator of phytoplankton biomass (Cloot and Ros, 1996, Forsgerg and Ryding, 1980). The amount of CHLa within the water is used as a measure of the concentration of suspended algae and micro-algae (phytoplankton). This indicator has been used as it has a measurable biological response in relation to environmental “stresses” that lead to algal blooms.

The method of detecting CHLa concentrations utilises the fluorescence of chlorophyll and accessory pigments. The YSI^{TM} 6820 sonde uses a Light Emitting Diode (LED) that emits blue light with a peak wavelength of approximately 470nm. On irradiation with this blue light, chlorophyll resident in whole cells emits light in the 650-700nm region of the spectrum (YSI-Environmental, 2008).

To quantify the fluorescence, the system detector uses a photodiode of high sensitivity that is screened by an optical filter that restricts exciting light from being detected when it is backscattered off of particles in the water. Without the filter, turbid (cloudy) water would appear to contain fluorescent phytoplankton, even though none were present (YSI-Environmental, 2005). This bias is particularly a problem in freshwater areas which contain high organic deposits such as dissolved humic material, usually present after rainfall (Millie et al., 2006). Using chlorophyll fluorescence is an indirect method for measuring chlorophyll concentrations, which can be affected by secondary factors such as the light history of the cells, accessory pigmentation, taxonomic grouping and nutrient availability (Kolber and Falkowski, 1993, Anderson et al., 2001). By monitoring these secondary factors, through fluorescence, it can be viewed as a method for monitoring the physiological status of algal cells (Cullen et al., 1997). Hence, in general chlorophyll fluorescence is considered representative of algal biomass and therefore high fluorescence readings are equated to high algal biomass (Lee et al., 2005).

Salinity and Conductivity

Salinity and conductivity measure the concentration of ions within a given water body. Conductivity is related to salinity and is temperature dependent increasing approximately 2-3% per °C (MHL, 2003). The YSI^{TM} sonde utilises a cell with four pure nickel electrodes for the measurement of conductance. This sensor is calibrated using a standard conductivity solution.

Temperature

The YSI^{TM} sonde utilises a thermistor that changes in resistance with temperature variation. No calibration or maintenance of the temperature sensor is required (MHL, 2003).

PAR-LITE Photosysnthetic Active Radiometer

The PAR-Lite was installed June 2007 for the purpose of measuring photosynthetic photon flux density otherwise known as PAR (Photosynthetically Active Radiation). This measurement represents the number of photons between 400 and 700 nm incident per square meter per second (Zonen, 2004). These photons can be used by algae for the process of photosynthesis. PAR-Lite measures the photons that are received from the entire hemisphere (180 degrees field of view) with the output being expressed in micro mol per second per square meter.

Thermistor cable

A thermistor cable has been deployed since the 4th December, 2007 to collect temperature data at approximately 1m intervals to the bed of the estuary. Miniature low thermal mass sensor nodes, capable of being integrated into a cable, form the sensing elements in the chain. Each node in the cable contains both a sensor element and the surface mount data conversion electronics. During calibration of these nodes thermally coupled potential errors due to temperature drift in the electronics can be fully removed.

Digital data from each node is sent by a custom serial bus to a power controller contained within the buoy floating on the surface. This power controller manages power to the sensor nodes as well as checking aggregating and formatting the data received from the sensors which then produces a stable serial ASCII RS232 output. The use of a custom low voltage bus to transmit raw data and a separate power controller, eliminates self heating effects at the senor nodes and means the power demand required to run the system is minimal. Typically the average power drain per node is 50 microwatts when producing a dataset every 5minutes. A commercially programmable data logger with an RS232 port is used to capture this raw data. The data logger then uses stored calibration data to convert the raw sensor data into final results, expressed in engineering units. This data is later retrieved via telemetry for analysis.

The system can be set to operate in calibration mode when a re-calibration of the cable is required. The cable with its sensor nodes is placed in a controlled temperature water bath for the purpose of calibration. The temperature range that can be monitored with this system is from 5 ^{0}C to 35 ^{0}C with a resolution of 15bits. With adequate calibration of the equipment and appropriate installation practices for the estuarine environment useable results are obtainable to an accuracy of ±0.002 ^{0}C.

Surface model generation

In order to generate hydrodynamic information (eg velocity, tidal prism, etc) and to determine the influence of hillshade on the probe location a surface model was created utilising Geographic Information System software, ArcGIS.
The surface model created utilised Hornsby Shire Councils Digital Elevation Model (DEM) data with a grid space of 25m resolution to 0 AHD was combined with bathymetry data sourced from Manly Hydraulics Laboratory. The surface model was created by interpolating between DEM data values (Bratt and Booth, 2002) from which a raster surface could be created. Rasters represent the surface as a regular grid of locations with sampled or interpolated values and are stored in a grid format as a rectangular array, consisting of uniformly distributed cells with z values. To create such a surface model use was made of “Topo to Raster” tool within ArcGIS. The interpolation method, “Topo to raster” is a method specifically designed for the creation of hydrologically correct digital elevation models and is based on the ANUDEM program, version 4.6.3. (Hutchinson, 1988, Hutchinson, 1989). The method principally uses an iterative finite difference interpolation technique. The program acknowledges that most landscapes have many hilltops (maximums) and few sinks (minimums) which results in a connected drainage pattern. Using this information “Topo to raster” uses the interpolation process that results in a connected drainage structure with correct representation of ridges and streams.

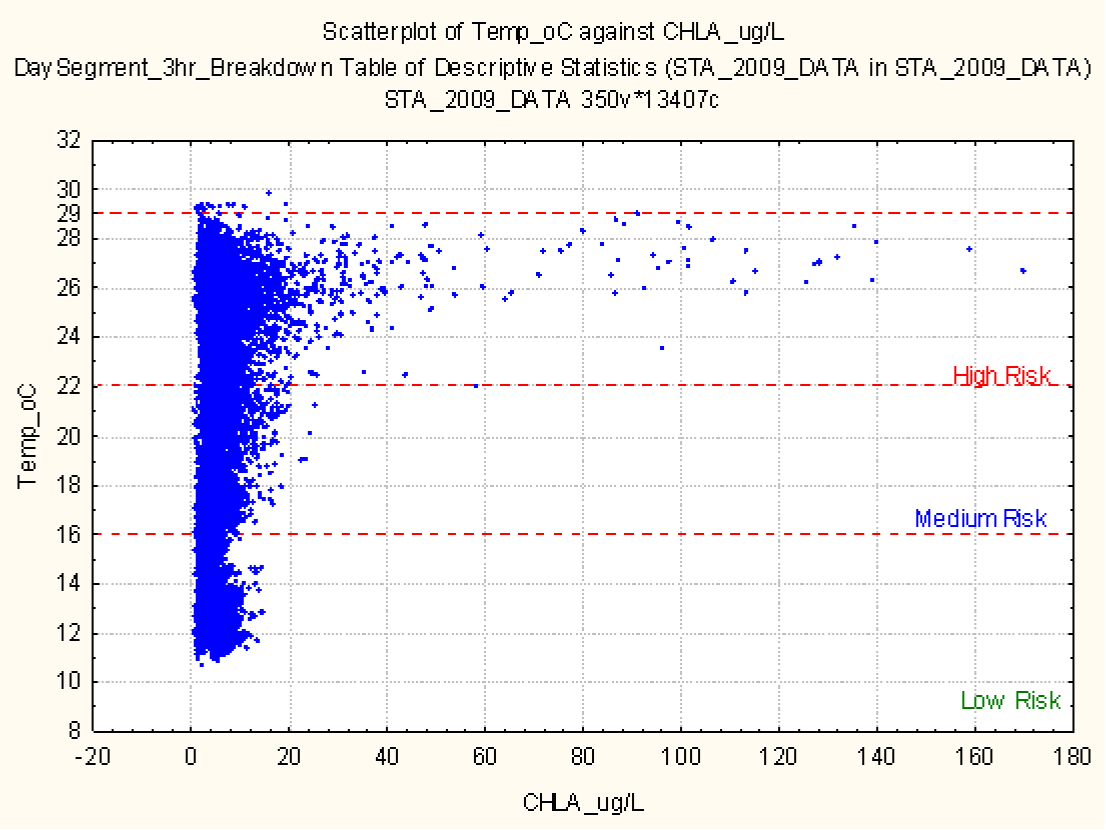
From this raster surface a TIN (Triangular Irregular Network) was determined. TINs consist of nodes that store z-values, connected by edges to form contiguous, nonoverlapping triangular facets (Bratt and Booth, 2002). Because these nodes are placed irregularly over the surface, TINs usually have a higher resolution in areas where a surface is highly variable or where more details is desired and a lower resolution in areas that are less variable (Bratt and Booth, 2002). It is for this reason that a TIN is created to enable a higher precision surface model of the Berowra estuary. The surface model was then used to calculate planimetric area, surface area and volume from which tidal velocities flows could be derived.

Results and Discussion

Temperature

Water temperature affects the range in which algal cells grow and survive, nutrient requirements, metabolic processes and thermal stratification (Beardall and Redden, 2007). Seasonal differences in response to increasing temperature and light have been shown to be significant in population composition and succession (Goldman and Ryther, 1976, Suzuki and Takahashi, 1995). Optimal temperatures (Figure 3) for the growth of mixed algal species within the Berowra estuary are in the range of 22 to 29°C.

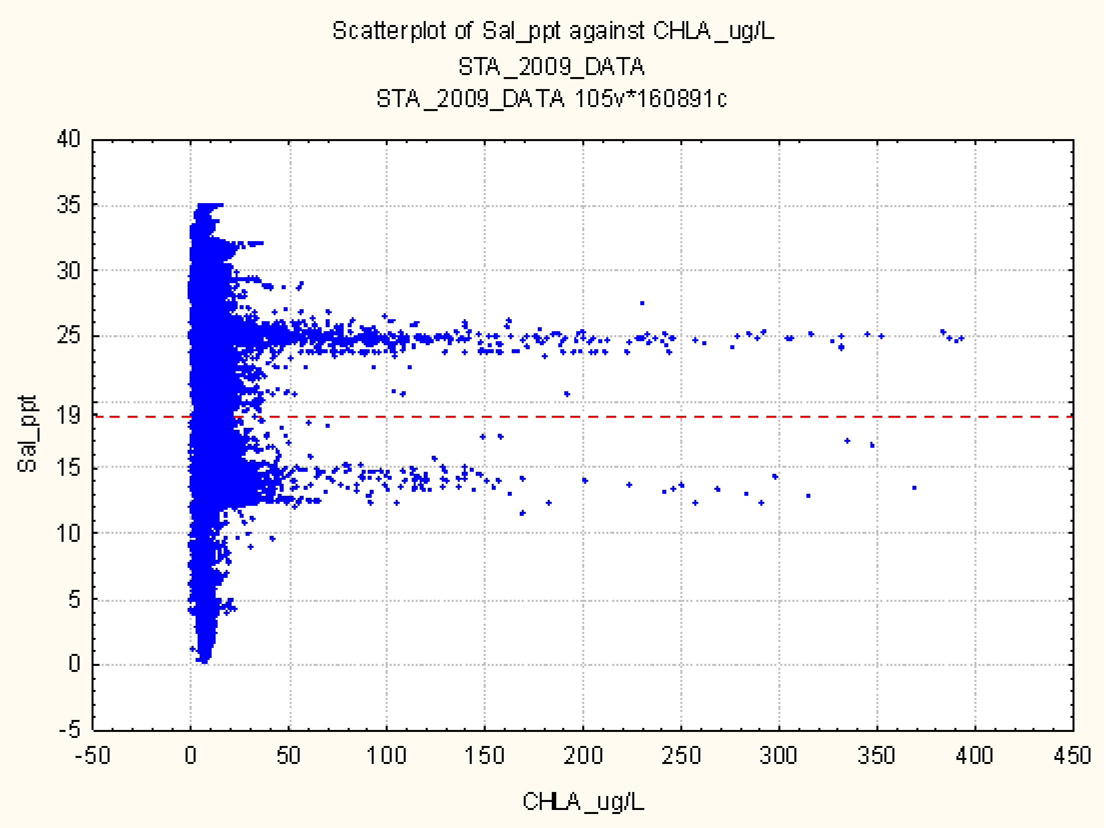
Figure 3 Temperature Vs CHLa



Salinity

Within the Berowra estuary there is a clear phytoplankton response (Figure 4) and preference for freshwater conditions (<19ppt) after rainfall and for saline conditions (>19ppt) during dry conditions. The freshwater conditions are considered to be periods of higher nutrient availability (from catchment runoff) and greater turbulence (from increased freshwater inflows). These freshwater conditions potentially favour species selection towards those that are fast growing such as non-motile species (eg diatoms) (Wong et al., 2007). During drier periods, when more saline conditions are dominant, nutrient access is decreased due to reduced turbulent transport, hence through vertical migration, motile species (eg dinoflagellates) can maintain access to marine bed nutrients and have a competitive advantage (Wong et al., 2007).

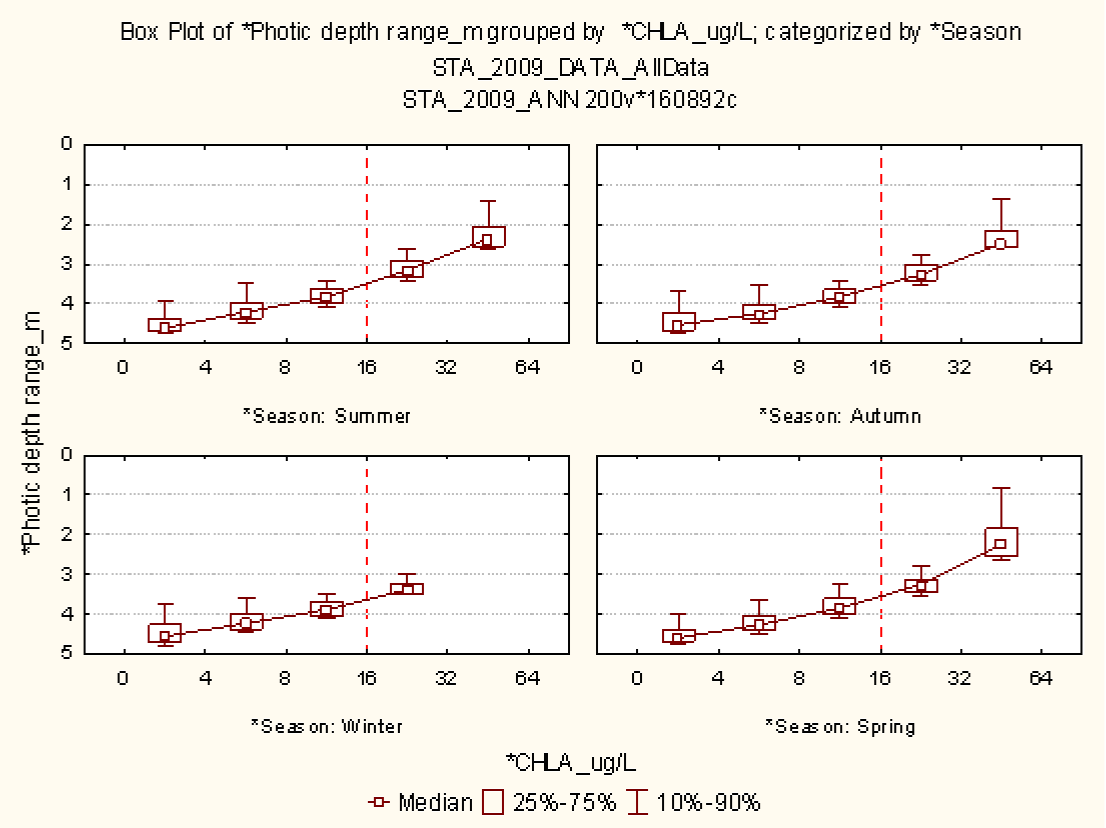
Figure 4 Salinity Vs CHLa



Light

The upper layer of the photic zone is the depth at which phytoplankton are photo inhibited whilst the lower layer is defined as the depth at which light reaches 10% of surface irradiance with consideration given to light extinction through the water column. The range between the two depths is considered to be the photic zone. From (Figure 5), it is shown that reduced photic zones and the highest CHLa concentrations are experienced principally in summer when warmer surface waters are also prevalent. Hence, the most favourable conditions for phytoplankton growth (>16ug/L) occur when the photic zone is limited (0-4m depth) and when warm summer surface waters are present.

Figure 5 Seasonal Photic depths Vs CHLa

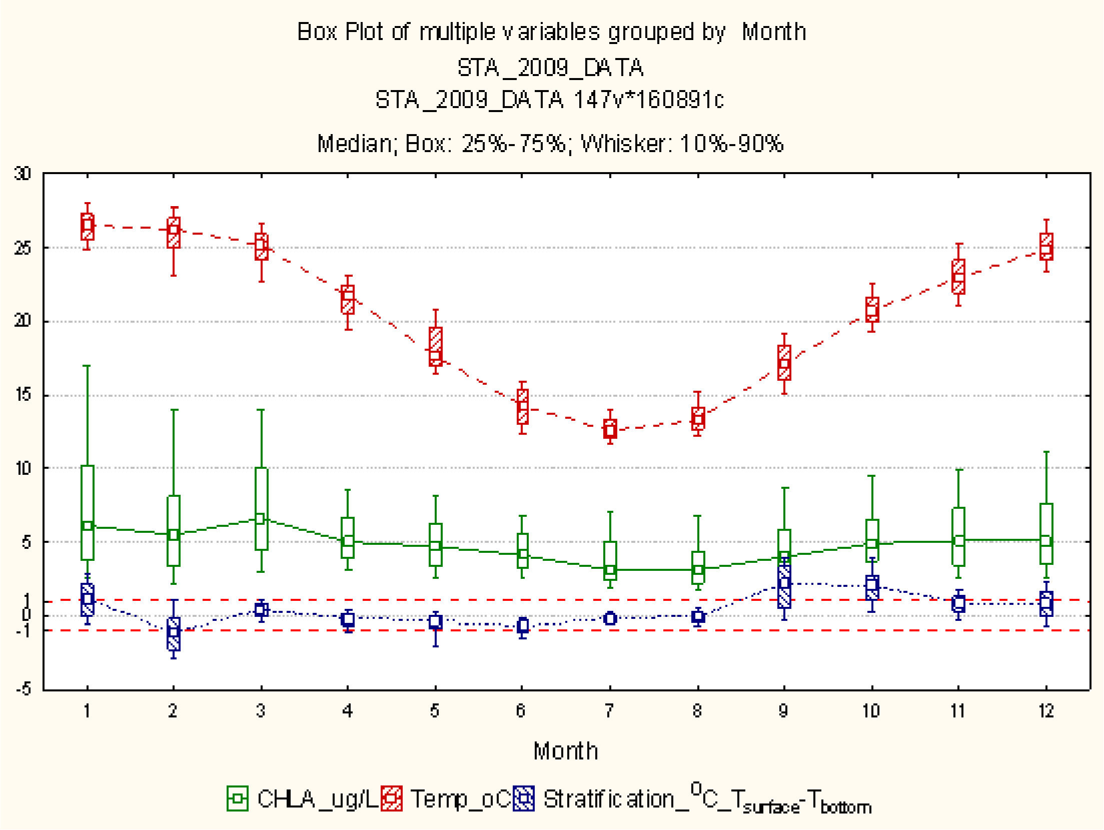


Season

The general pattern of species succession during summer through to winter is considered as follows within the Berowra Estuary (adopted from Reynolds, 1984). Initial biomass of phytoplankton is low in late spring, with the onset of summer stratification, phytoplankton that are able to utilise the resources of light and nutrients are favoured. At this point the supply of resources (which have built up during winter periods) is high and demand is low, thus favouring initial colonisation by populations of opportunist species. As the biomass and subsequent demand increases, resources (eg light or nutrients) decrease and the exploitative loss processes become more prevalent towards the end of summer, so that the more conservative slower growing species are progressively selected. Demand then outweighs supply, light and nutrients become limiting and hence conservative species become the phytoplankton that are selected over the winter period especially with the onset of well mixed cooler water periods. During the winter periods migratory movements are of advantage within the flagellates in maintaining potentially favourable access to nutrients within the sediments of the estuary floor and light at the surface.

Following summer is autumn which has a characteristic reduction in day length and radiation intensity which evidently leads to a cooling of the atmosphere and water temperatures. With the drop in mean air temperatures a net heat loss from the estuary surface also occurs and thermal instability as cooled water near the surface sinks to be replaced by the warmer water at depth by convection, gradually mixing the surface and bottom waters. Accordingly, the point at which the water column becomes isothermally mixed is generally within the Autumn period around March/April (Figure 6).

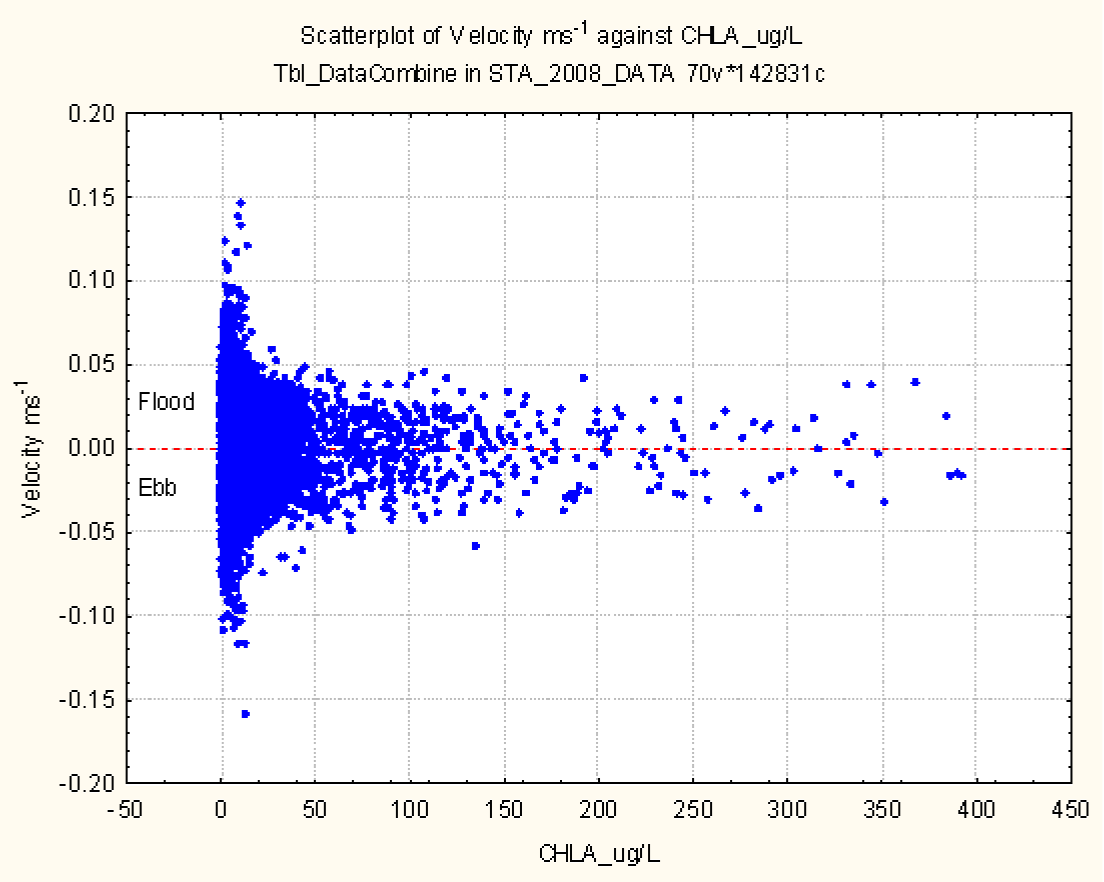
Figure 6 Seasonal influences on CHLa



Tidal Velocity

The role of horizontal transport is another important consideration. Estuarine velocities calculated within the Berowra estuary indicate low velocities (approximately <0.05ms^{-1}, Figure 7) in either ebb or flood tide have the greatest probability of high concentrations of CHLa occurring at a 15 minute timestep. Given peak CHLa concentrations are observed during periods of low velocities it is considered the phytoplankton are responding to locally favourable low flow conditions.

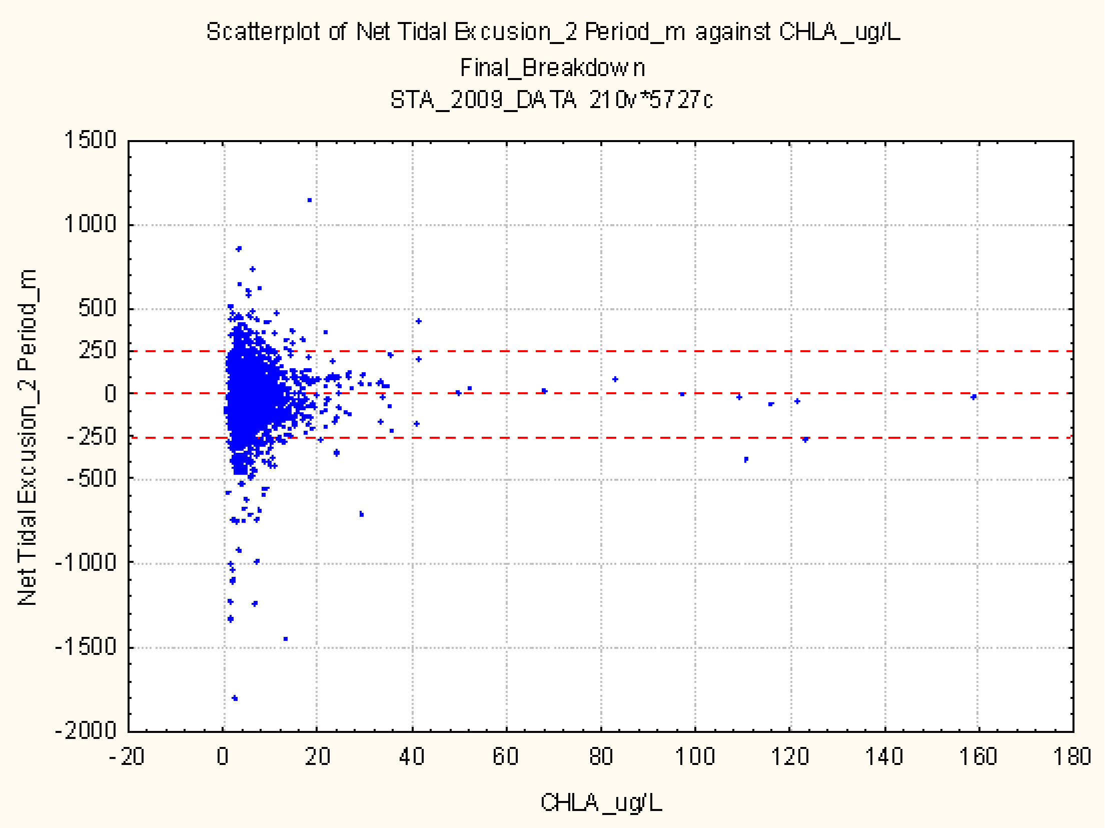
Figure 7 Estuarine velocities Vs CHLa



Tidal Excursion

Tidal excursion is considered to be the net horizontal movement of an oscillating ‘algal particle’ over two tidal periods. During periods of small net excursions (<250m and >-250m) the highest concentrations of CHLa are observed (Figure 8). In addition, high CHLa concentrations are not associated with any particular net tidal movement i.e. downstream or upstream.

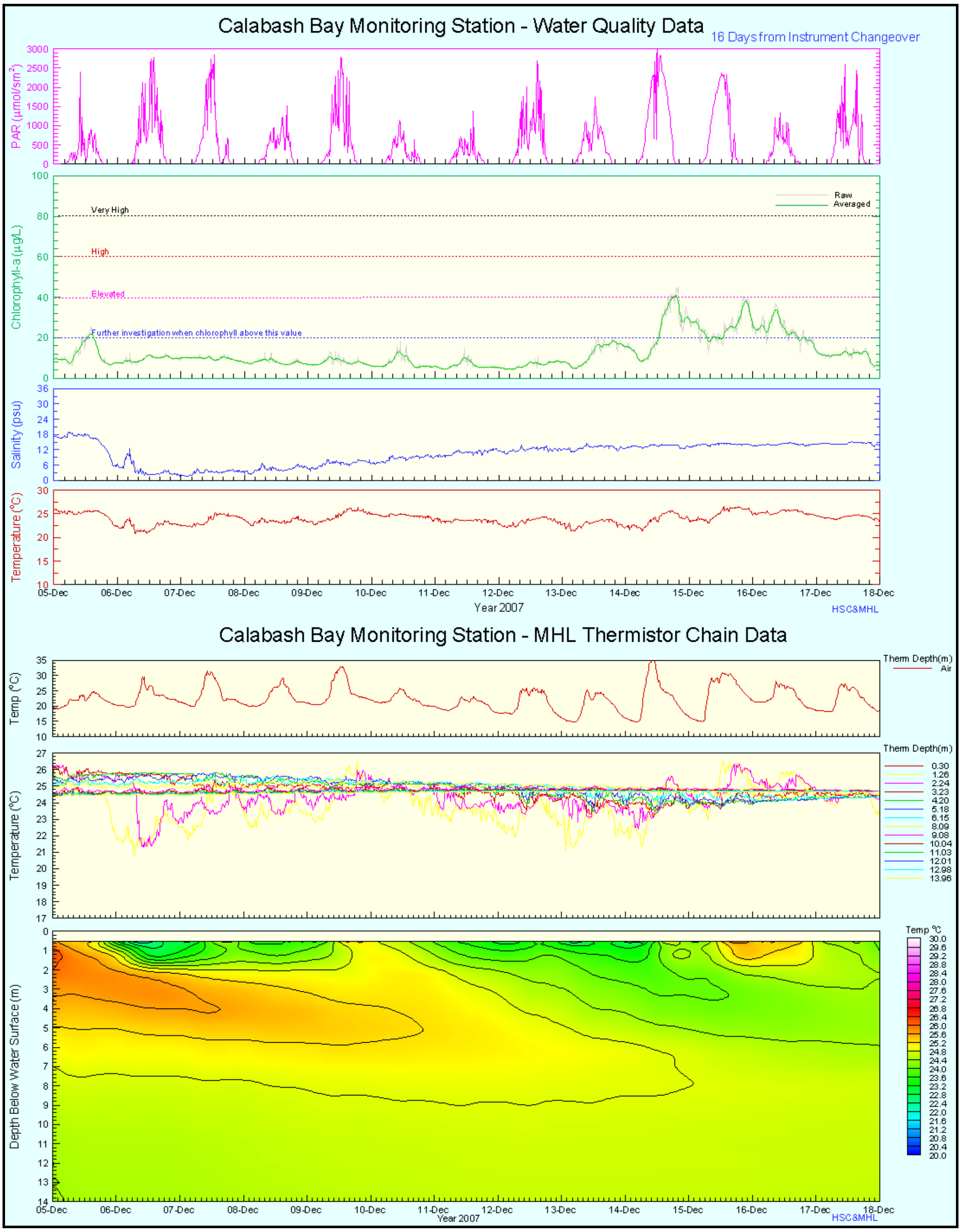
Figure 8 Net tidal excursion Vs CHLa



Algal Blooms

The formation and spatial distribution of phytoplankton blooms in estuaries are controlled by local mechanisms (e.g. light, grazing, etc) which determine the phytoplankton production-loss balance and transport mechanisms which govern the spatial distribution of phytoplankton biomass (Lucas et al., 1999a). Within the Berowra estuary, the phytoplankton community structure will remain reasonably diverse and stable in response to relative steady state conditions of resource spectra. Transitions to periods of rapid community reorganisation and stimulation of higher growth rates occur, hence bloom, when these resource spectra exceed limiting conditions (eg increased temperature) or are influenced by a spasmodic event (eg rainfall, wind) (Figure 9). Hence, the basic requirement for bloom development is the existence of favourable environmental conditions (Sole et al., 2006). However, this ‘switch’ from steady state to high growth periods does not conform to a single predictable process pattern. This is because the limiting or critical resource (eg light, nutrients) can vary or are triggered at different times.

Figure 9 Algal bloom responding to rainfall and high water temperatures



Conclusion

Phytoplankton are a natural phenomena within estuarine ecosystems that may proliferate during favourable environmental conditions (e.g. temperature, light, etc) or in response to anthropogenic activities (e.g., nutrient discharge, etc). Favourable physical and chemical parameters include periods of minimal flushing, warm temperatures and nutrient availability. With regard to biological factors competition, predation and succession may play an important role in allowing the dominance of a particular taxa.

When particular species dominates a phytoplankton community, they accumulate and may form visible and dense biomass films at the surface of the estuary and are considered to be an algal bloom. When the proliferating species produces toxins that threaten both natural and human health the bloom it is referred to as a harmful algal bloom (HAB). These HABs have led to fish kills, hypoxia and estuary closure.

The Berowra estuary is an important natural resource supporting recreational, commercial, natural and scientific endeavours. Therefore, it is important to maintain and improve water quality and implement effective catchment management initiatives to ensure the long term sustainability of this resource. Modelling the direct processes that contribute to phytopklankton blooms is difficult, as the underlying interactions are not fully understood and are extremely complex and non-linear.

Long term collaborative monitoring, experimental assessments, and modelling of phytoplankton dynamics over appropriate spatial and temporal scales is essential for developing realistic, ecologically sound, and cost effective phytoplankton management strategies for the Berowra estuary which is impacted by both anthropogenic and climatic perturbations. To ensure these strategies are implemented will require a high degree of coordination between different initiatives, agencies and use of resources to obtain the best environmental outcomes. This will pose a significant challenge to natural resource managers, the community and political processes.

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