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SUBJECT:

"Evidence that algal biomass is primarily controlled by stratification and the light environment in the Swan River Estuary"

In response to recent public interest, and particularly to some inaccurate claims being made within the media, a brief summary of the work undertaken to examine the controls on algal variability over the last decade in the Swan River is presented. The analysis should be seen as preliminary findings and the work is currently under review by leading experts. However, we believe the results are significant and should be used to provoke further discussion on the future management of the Swan River.

Yours sincerely

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Evidence that algal biomass is primarily controlled by stratification and the light environment in the Swan River Estuary.

Background

The Swan River Estuary in Western Australia receives water from the Avon and Swan Coastal Catchments, which have a total area of more than 120,000km², and supports Perth's 1.5 million people. Most of the annual rainfall occurs between April and September. River flow patterns closely reflect rainfall, with 95% of annual flow occurring between May and October.

The estuary is extremely seasonal as a consequence of the low mean tidal range (0.6m), narrow passage to the sea and highly seasonal runoff. As a result, stratification typically occurs under a number of circumstances (Hodgkin, 1987) . In winter, the seasonal discharge from the tributaries effectively isolates and traps the more dense salt water at the bottom of the water column, resulting in stratified conditions in the upper estuary. As river flow increases, waters of the upper estuary are well flushed, yet stratification remains in the deep basins of the middle estuary, with a halocline evident at a depth of about 5m (the depth of the sill at Fremantle) (Hodgkin, 1987). Intruding marine water driven by tides and barometric pressure keep the lower estuary well mixed and stratification only becomes evident when discharge is high. When river flow decreases in the late winter or spring, brackish water intrudes into the middle estuary and the salt wedge moves progressively upstream until the summer condition is re-established.

Since European settlement in Perth in 1827, the Swan Estuary catchment, hydrodynamics and nutrient status have been altered significantly. Dredging of the estuary (including permanently opening the mouth of the estuary at Fremantle), drainage of wetlands and infilling, dam and weir constructions, clearing of native vegetation and fertiliser addition within the surrounding catchment have altered the natural functioning of the system. As a result, deterioration of water quality particularly in the upper reaches of the Swan River, threatens the recreational and commercial value of the system (John, 1987). In particular, dinoflagellate (eg *Karlodinium micrum*, autumn 2003) and cyanobacterial (e.g. *Microcystis*, summer 2000) algal blooms in recent years have resulted in fish kills and closure of the river to the public.

In 1994 the Swan Canning Cleanup Program (SCCP) was launched to study the problem, determine how to reverse any deterioration that has occurred and develop a program for the effective cleanup of the Swan-Canning System (Swan River Trust, 1999). Subsequently, an action plan was released in 1999 with the key objective to lower nutrient inputs to reduce algal blooms (Swan River Trust, 1999). In September 2007, the Swan and Canning Rivers Management Act 2006 and associated legislation came into effect. Part of this was a policy to reduce loads of phosphorus into the estuary system, including the phasing in of a complete ban on soluble phosphorus (P) fertilisers.

Numerous studies have attempted to understand the physical, chemical and biological factors which regulate algal productivity in the Swan River Estuary (Chan, 2006, Thompson, 1998, Thompson, 2001, Thompson and Hosja, 1996, Twomey and John, 2001). With the Swan River's extreme seasonality in its hydrology, it is not surprising that salinity has been considered the "master factor" (Hodgkin, 1987), controlling phytoplankton biomass and succession over an annual cycle. Further studies have identified rainfall and river flow as key determinants of phytoplankton succession from diatoms, chlorophytes, diatoms and finally to dinoflagellates and cryptophytes in late summer-autumn (Thompson, 1998). Nitrogen has been identified as the nutrient with the greatest potential to limit algal biomass, with nitrogen up to 20 times more limiting than P in mid summer (Thompson and Hosja, 1996). Phytoplankton blooms in the upper estuary are generally considered to develop in response to nutrient concentrations, thus the key management objective is to reduce the concentrations of nutrients in the estuary (Swan River Trust, 1999). Although this relationship has been demonstrated for numerous sites around the world, there is limited evidence that biomass and succession in the Swan River is currently controlled by nutrients.

To examine the controls on algal variability in the Swan River an independent study was conducted by the Centre for Water Research during 2007.

Methods

The study analysed available data collected by the Swan River Trust from 1995 to 2004 inclusive. Data in the estuary was taken from the nine major sampling sites along the Swan and 24 tributaries.

Annual flow was estimated using daily summed flows of the Avon, Ellen Brook, Bennett, Helena, and Bayswater tributaries. These tributaries account for greater than 95% of the flow to the Swan Estuary. Total Nitrogen (TN) and Total Phosphorus (TP) nutrient loads over the same period have been calculated by multiplying daily flow and nutrient concentrations using the eight major tributaries (Avon, Ellen Brook, Bennett, Helena, Bayswater, Jane Brook, South Belmont and Sussanah Brook). These loads were also normalised by the flow experienced within the year to provide an estimated mean nutrient concentration entering the Swan Estuary from tributaries.

Mean annual TN and TP concentrations were calculated by averaging surface TN and TP concentrations integrated across the whole estuary. Years were classified into intermediate, low or high TN and TP concentration years.

To explore the effect of stratification on phytoplankton, the estuary was partitioned into sections, depending on the nature of stratification. Two years with typical nutrient loading were analysed (1995 and 1998), as well as one year with high nitrogen and average phosphorus (1996), one year with high phosphorus and average nitrogen (1997) and one year with below average nitrogen and phosphorus (2001), allowing all extremes and intermediates of annual nutrient concentrations to be analysed. Fortnightly salinity profiles at the nine estuary sampling stations were used to determine locations of stratification regimes. Stratification regimes have been classified as marine, part marine, stratified, in front of the salt wedge, and fresh.

Biomass of the different algal groups was compared with nutrient loading, nutrient concentrations within the estuary itself, the salinity and the light climate (where the light climate is controlled by Dissolved Organic Carbon, DOC, concentrations as presented in the experimental work in the Swan by Kostoglidis et. al. (2005).

Results

The data show that N and P loads into the estuary primarily correlate with flow (r^2=0.97, for TN and r^2=0.93 for TP), and there was no significant change in the annual 'average' inflow nutrient concentrations over the period 1995 and 2004.

Contrary to the prevailing hypothesis that nutrients control phytoplankton abundance, there was no correlation found between TN and/or TP within the estuary (or loading in the inflows) and phytoplankton abundance, averaged over seasonal (3 months) or annual time periods (Figure 1). This was found to be true when looking at the estuary as a whole, or at each of the individual salinity regimes within the estuary. Further, the total abundance of the dominant algal groups (dinoflagellates and diatoms) was actually significantly higher in the intermediate and low nutrient years (Figure 2).

The highest algal biomasses were typically observed near the peak of stratification and in front of the salt wedge (ie. in the mid-reaches of the estuary). The spatial variability in the concentrations was further examined by looking at changes in N, P, and light (Figure 3). The results indicated the reason high concentrations were observed in the mid-reaches is due to sufficient nutrients and ample light. Further downstream the nutrients decrease and further upstream the light conditions are unfavourable.

This was placed into the context of algal growth by plotting the extent of limitation due to nutrients and light (following the procedure previously used for the Swan Estuary by Robson and Hamilton, 2003). The results indicate that the high levels of available nutrients are not limiting growth and that light is a major limiting factor – the light limitation estimate highly correlates with the observed peak biomasses for both diatoms and dinoflagellates.

The role of light limitation supports the observed negative trend between nutrient loading and biomass (Figure 2) since DOC loading correlates highly with nutrient loading from the catchment – that is nutrient levels increase as light availability decreases.

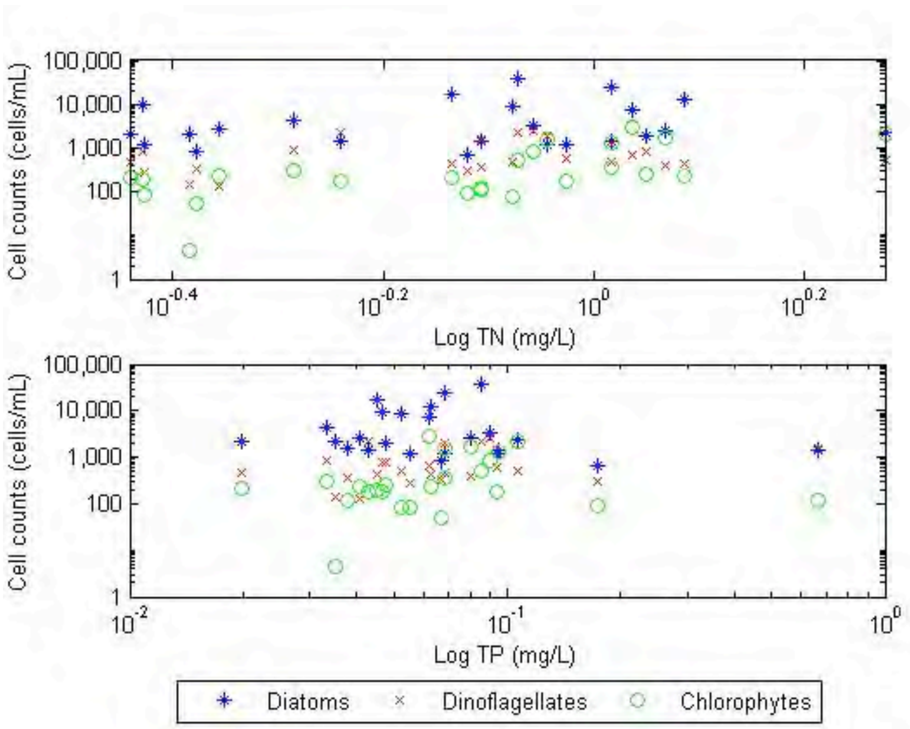

Figure 1: Correlation between a) TN, b) TP concentrations and dinoflagellate, diatom and chlorophyte cell counts in different stratification regimes.

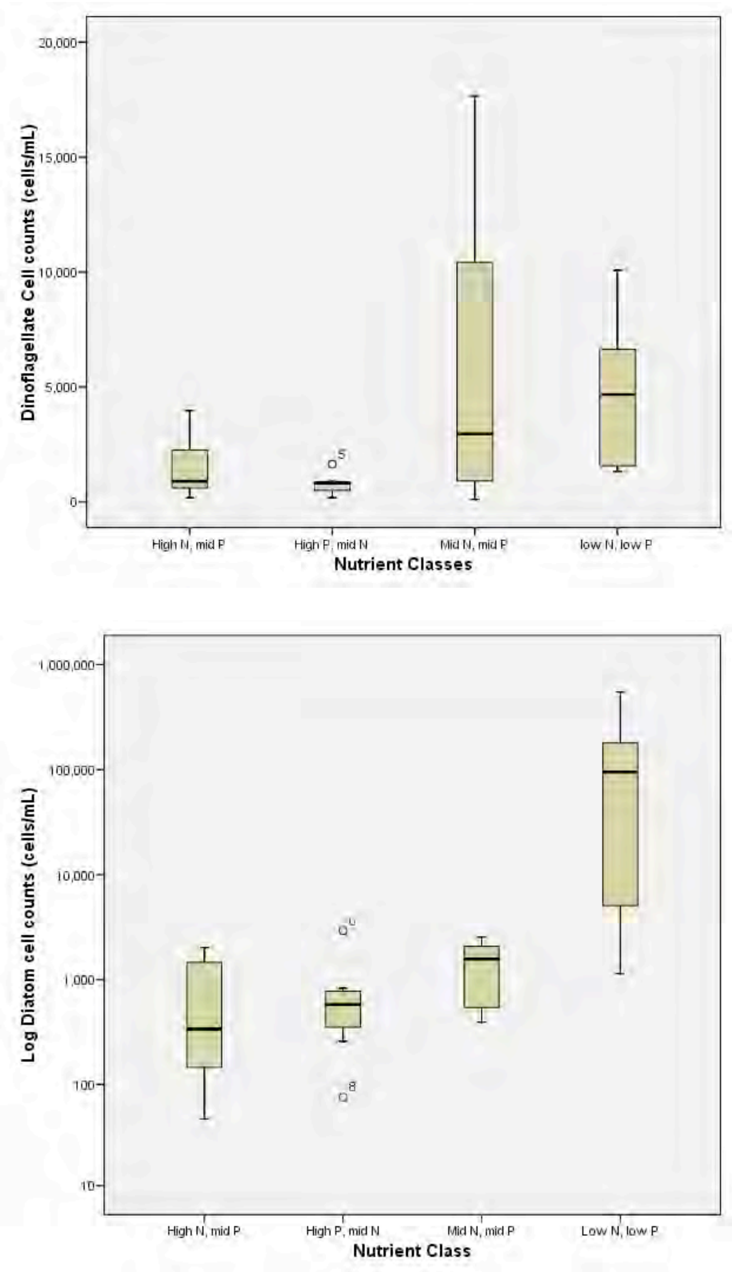

Figure 2: Box plot of a) dinoflagellate and b) diatom cell counts in summer (Dec-Feb) in front of the salt wedge in different nutrient classes (this region and period was identified as the most significant contribution to annual total biomass). Black bar indicates mean cell count, box boundaries indicate standard deviation and the whiskers indicate the total variability within the sample set.

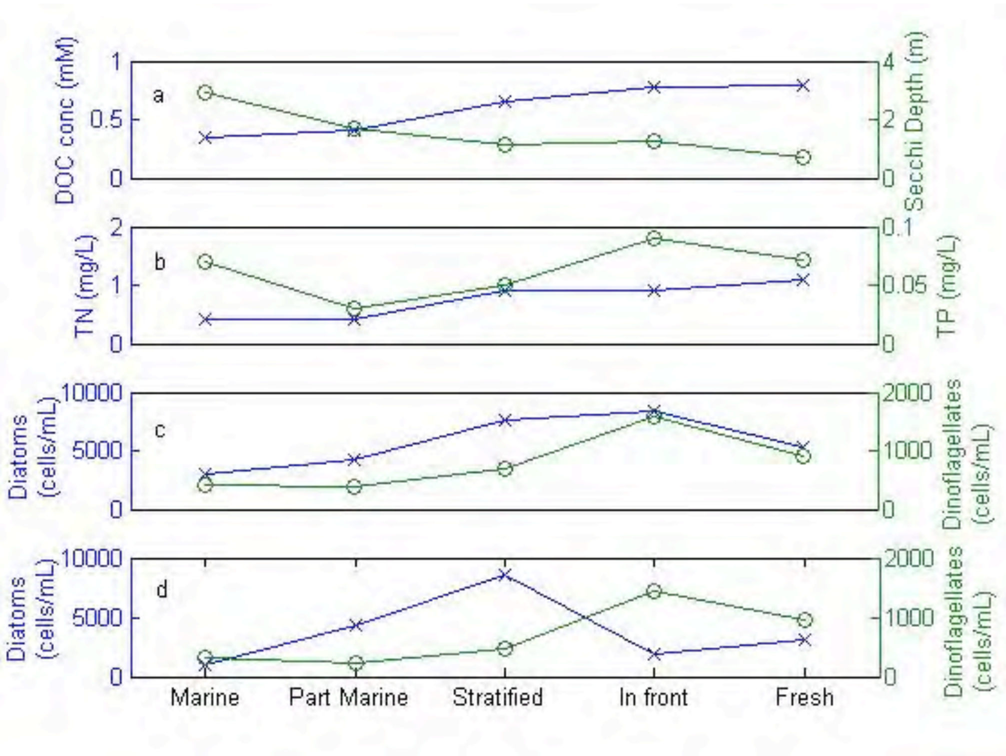

Figure 3: Light, nutrients and cell counts in stratification regimes. a) DOC concentration (x) and Secchi depth (o), b) TN (x) and TP (o) concentration c) Diatom (x) and dinoflagellate (o) cell counts across all years, d) Diatom (x) and dinoflagellate (o) cell counts in all years excluding 2001.

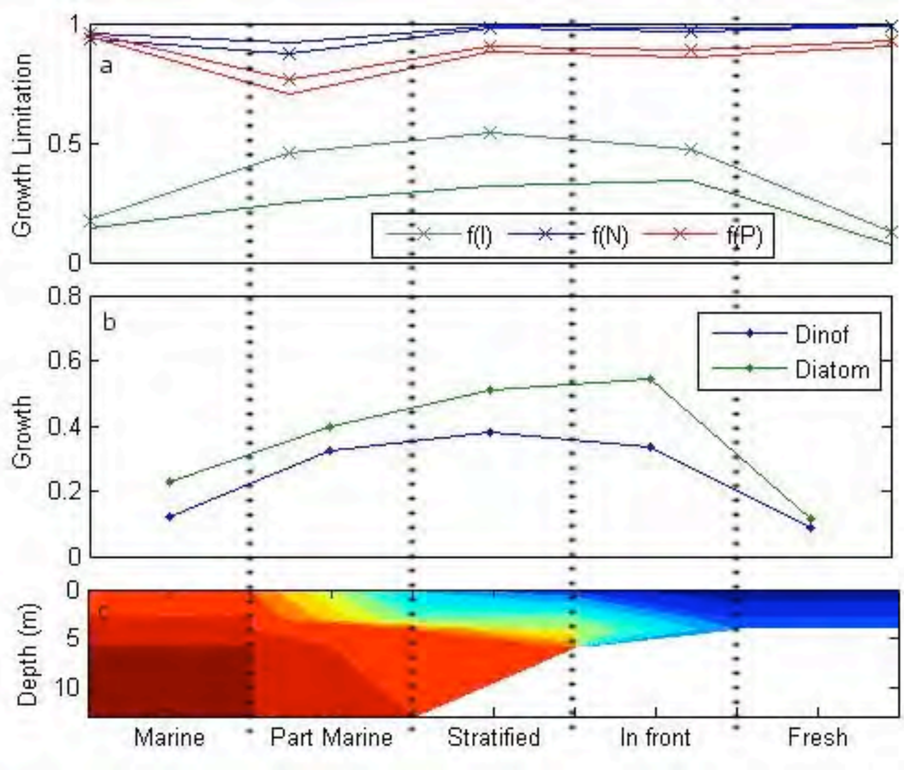

Figure 4: a) Irradiance (f(I)), Nitrogen (f(N)) and phosphorus (f(P)) limitations to phytoplankton growth as a function of horizontal position in the estuary. b) Daily growth rate of dinoflagellates and diatoms, c) Stratification Regimes.

Implications:

These findings suggest:

- Nutrients are sufficiently abundant within the Swan River such that they alone are unlikely to ***control*** the formation of blooms; they may however dictate the final biomass reached during a bloom event;

- Reduction of nutrient loading by 30% is unlikely to change the system to become nutrient limited as the system has an existing large store in water and sediments – that is bloom formation will continue to be controlled by light and salinity even under ambitious nutrient reduction targets.

- The light and salinity environment is expected to be significantly impacted given that current climate change scenarios for the south-west of WA depict considerable reductions in the amount of flow, and increased flow variability. In addition, the reduction of nutrient loading under reduced flow conditions associated with climate change could easily be more significant that nutrient reductions due to management strategies, such as fertiliser bans.

- These results indicate that there is a great need for further scientific understanding on the interplay between salinity, light (as influenced predominantly by DOC), and nutrients in the Swan River Estuary under climate change scenarios to enable the recommendation of suitable management options.

- These results should not be interpreted to mean that excessive loading of nutrients to the estuary is acceptable. Nutrient reduction targets are potentially an important part of future management actions but should undergo review based on these findings and potential climate change pressures that have been identified for the region.

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