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Surface Chlorophyll Patchiness across Sepanggar Bay: Relationships with Turbidity and Depth

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ABSTRACT

The prevalence of harmful algal blooms (HABs), poses a considerable risk to public health and the livelihood of local fishers centred on Sepanggar Bay (Sabah). While HABs appear ostensibly during the NE Monsoon, there is no information on what may control their mesoscale distribution and production across Sepanggar Bay. For this study, we hypothesize that shallow sediment resuspension of a viable microphytobenthic population, along with potential germination of encysting harmful algae, control the mesoscale surface patchiness of chlorophyll-a across Sepanggar Bay. A ‘snap-shot’ over the NE Monsoon, of surface chlorophyll-a, together with turbidity and oxygen concentrations was produced from of 34 sampling stations chosen randomly across the bay’s regions. For rapid processing and measurement, chlorophyll-a, and turbidity were taken from surface colour reflectivity, using the phone app HydroColor™. The remaining variables surface temperature, salinity, and oxygen concentrations came from a probe. Both turbidity and chlorophyll-a showed considerable structure across the bay with depth. In general, there were good correlations between depth (inverse), turbidity (positive), and surface oxygen concentrations (positive) with chlorophyll-a across the bay, but with low chlorophyll-a outliers near a water village. The reasons behind the structure and the above correlations are elaborated in the paper.

Introduction

Sepanggar Bay is the gateway to Kota Kinabalu, the capital of Sabah containing a major port, resorts, coastal housing, and water villages. The bay also supports an important fisheries resource, providing both farmed and fished seafood. Given the prevalence of harmful algal blooms (HABs) during the NE Monsoon (Adam *et al*., 2011) arguably the result of surrounding anthropogenic pressures, the risk to public health is high. The HAB situation is being monitored at some sites by local authorities. However, HABs distribution that across the bay is patchy (*pers. obs.*), like most phytoplankton mesoscale phenomena (Parsons *et al*., 1981). Without an understanding of microalgal patch dynamics, it is difficult to access the accuracy of the monitoring program as well as locating particularly vulnerable areas across the bay.

Current theories of embayment phytoplankton patchiness are based on a balance between the need for relatively shallow mixed layer stability (thermocline) and the entrainment of nutrients from deeper waters by tidal or wind generated turbulence (Pingree *et al.*, 1975, Parsons *et al.*, 1981). The distribution of the bloom then becomes a function of the patchy distribution of turbulent forcing factors. For example, the position of islands, peninsulas, storm fronts and fetch across a bay area will add structure to the balance between tidal currents and wind generated turbulence (Pingree *et al.*, 1975, Parsons *et al.*, 1981). Of course, surface nutrient supply is not isolated to bottom entrainment. Rivers can both directly supply nutrients and add to the stability of surface waters, which in turn leads to algal blooms but only within the immediate vicinity of the river mouth (Parsons *et al.*, 1981).

The above conceptual model, however, is based on relatively deep coastal waters and embayments. Little consideration has been given to embayments that support significant areas of shallow water. Shallow waters are susceptible to sediment resuspension from wind, waves and tides beyond a certain critical value (Ward *et al.*, 1984). With sediment resuspension also comes associated light adapted microphytobenthos (Ubertini *et al.*, 2012), and the potential for encysting HAB species to germinate, should water conditions of temperature and nutrient be right to dominate the assemblage (Adam *et al.*, 2011). It is possible, that such a process may falsify the surface mixed later stability/entrainment model of microalgal mesoscale patch dynamics. In place, we propose a model using surface chlorophyll-a concentrations to measure microalgal biomass based solely on the bathymetry, and possibly constrained by low surface water light levels, the result of highly turbid waters from suspended sediments.

Aims

The study seeks to test the conceptual model that surface microalgal structure across Sepanggar Bay (Kota Kinabalu, Sabah, Malaysia), and subsequent non-light limited production, is primarily the result of general tidal, wind and wave generated supply of a viable microphytobenthic population from sediments to the surface waters. Such a model produces an inverse relationship between depth and surface chlorophyll-a and a positive relationship between surface turbidity and oxygen concentration. The constraints being a relatively invariant surface mixed layer depth, insufficient or relatively invariant rates of surface oxygen ventilation, non-light limited growth, and an accessible microphytobenthic populations and encysting harmful algal across the bay.

Methodology

Sampling design

The survey is designed to approximate a 'snap-shot' in time of surface turbidity and chlorophyll-a structure across the bay, in relation to both water column and bathymetric state variables. For that, a stratified random design is employed, using three separate boats to visit 34 stations (>200 m apart), across five regions - coastal shallows, port area, Pulau Gaya water village, the bay entrance, and the remaining body of the bay, over 3-4 hours towards the end of a rising neap tide (Leeuw and Boss, 2015).

Measurements

All three boats recorded turbidity, temperature, salinity, using a probe (Hydrolab™), as well as chlorophyll-a and turbidity using the HydroColor™ reflectance phone 'app' (Leeuw & Boss, 2015). The algorithm for chlorophyll-a is based on calibration taken from surface waters around Sepanggar Bay (Gallagher, 2015). The boat with the least number of sampling stations was also charged with taking oxygen concentration profiles (Hydrolab™). Depth of the water column was measured with Speedtech® Depthmate Sounder, and the surface mixed layer depth was determined at the position of a relatively major discontinuity in temperature depth profiles. Any aberrant chlorophyll-a data was identified and filtered out by identifying large inconsistences between turbidity measured by Hydrolab's™ nephelometer and HydroColor's™ reflectance values, and the quality of the photographs used to determine those values.

Data analysis

Contours of surface chlorophyll-a and turbidity across the bay are constructed in PAST© v3.10, using inverse distance weighting across 5 neighbouring sites. A topographical map of the Sepanggar Bay area, taken from Google Maps™, were overlaid on the contours in Adobe Photoshop CS6® image editor. All regressions are based on reduced major axis (RMA) linear regression models to account for errors in both the abscissa and ordinate variables.

Results and discussion

The major state variables surface salinity and temperature across the Bay were fairly uniform — 29.2 ‰ to 31.9 ‰ and 29.7 ˚C to 30.9 ˚C, with no obvious influence from river discharge. The spatial structure of both surface chlorophyll and turbidity broadly follow the same pattern across the bay (Figure 1). High concentrations in chlorophyll-a and turbidity are primarily located within the mainland's littoral zone, in particular the area surrounding the mouth of the river (Figure 1) but are still independent of one another. For example, using a 67:1 turbidity or suspended particulate matter:chlorophyll-a ratio (Creitz and Richards, 1955), chlorophyll-a concentrations never exceed 0.4 % of the suspended particulate matter (mg l^{-1}) or equivalent turbidity units (NTU). There is also a suggestion of a plume of relatively high chlorophyll-a concentrations and turbidity emanating into deeper waters: marked by stations 7, 4, 18, 17 near the center of the bay. Nevertheless, a moderate negative relationship of surface chlorophyll-a and turbidity with depth is maintained across the bay, but not with the surface mixed layer depth (**Table 1**).

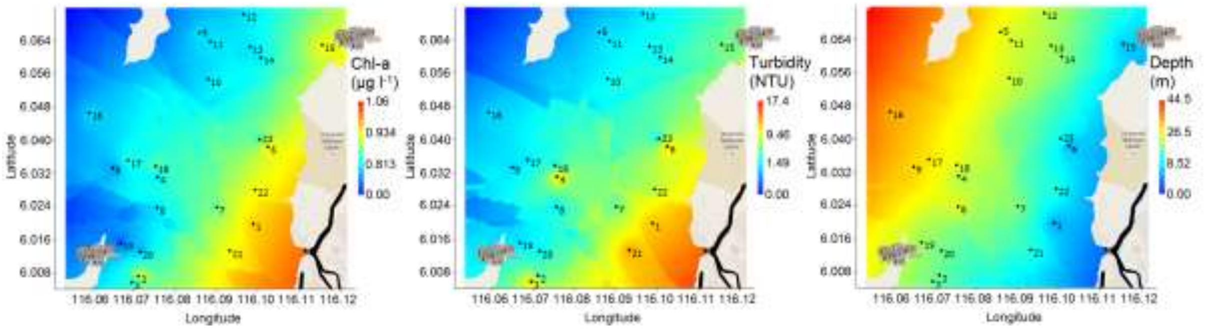

Figure 1. Contours showing the extrapolated distribution of surface chlorophyll-a, turbidity and depth across Sepanggar Bay. The numbers refer to the station name; the black lines represent a coastal lagoon (bottom of the figure) and the Inanam river that extends through the catchment.

Table 1. Pearson correlations between chlorophyll-a, turbidity with bathymetry and surface mixed layer depth.

	Depth (m)	Mixed Layer Depth (m)	Surface Turbidity (NTU)	Chlorophyll-a concentration (µg l^{-1})
Depth (m)		0.04424	0.00243	0.00063
Mixed Layer Depth (m)	0.42315		0.6006	0.28631
Surface Turbidity (NTU)	-0.60083	-0.1152		0.029892
Chlorophyll-a (µg l^{-1})	-0.65877	-0.2322	0.45315	

It would then appear that the supply of microalgae to the surface waters of Sepanggar Bay is consistent with resuspension of surface sediments and associated microphytobenthic algae from waves, wind and tidal forces. Furthermore, the poor correlation of chlorophyll-a concentrations with the mixed layer depth indicates that the supply overwhelms any effects from dilution. There is also a suggestion that the resuspended material may act an inoculum to the rest of the bay, as evidenced by afore mentioned central plume emanating from the littoral zone. The importance of this finding to the proliferation of HAB sedimentary cysts is given further strength, in that the resuspended microalgal population appears to be viable, i.e., there is positive relationship between chlorophyll-a and surface oxygen saturation across the bay (Figure 2).

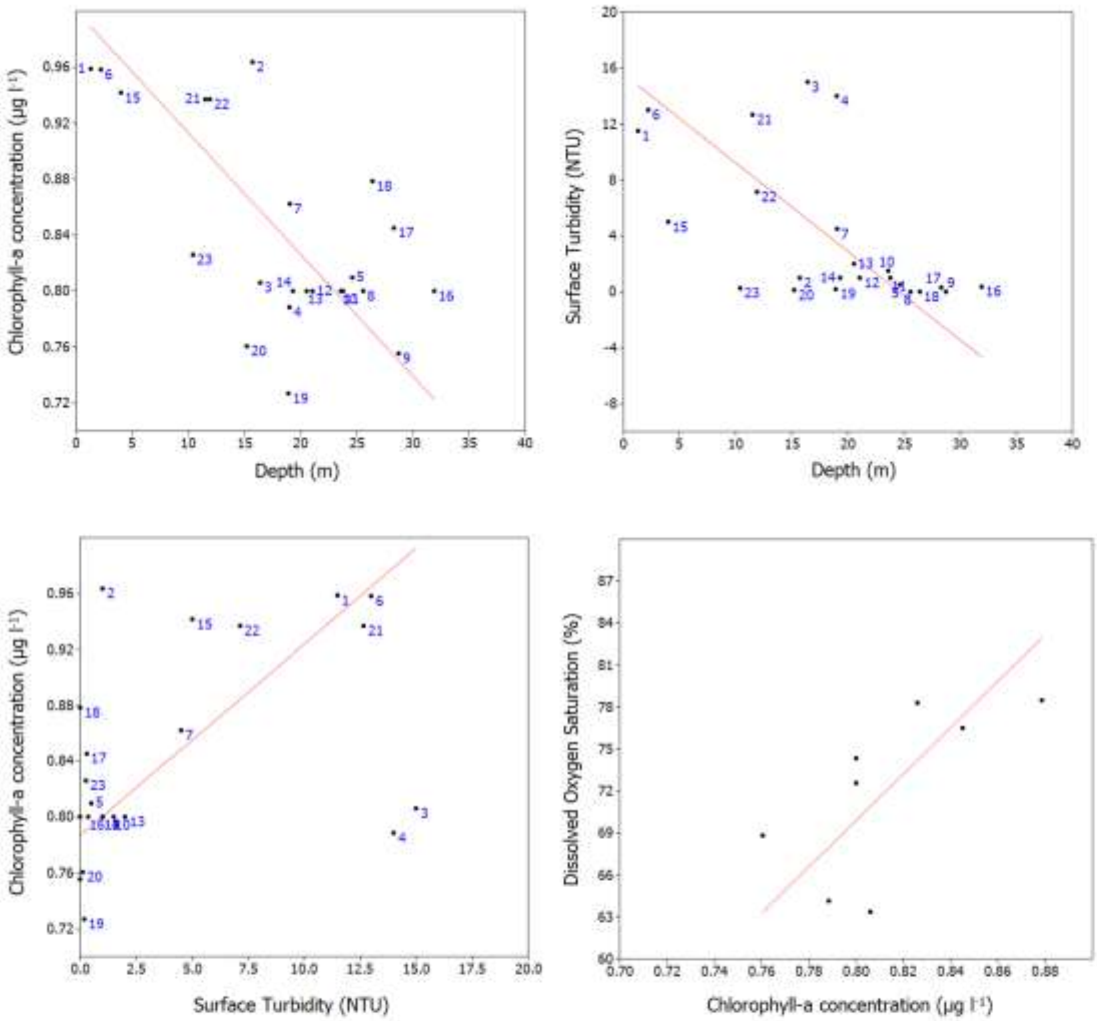

Figure 2. RMA regressions for surface chlorophyll, turbidity with depth and surface oxygen saturation across Sepanggar Bay (Kota Kinabalu, Malaysia). Note the outliers at stations 3 and 4 for Turbidity vs depth and Chlorophyll-a vs Turbidity (see text for discussion).

There is some evidence to suggest, however, that there may be regions across the bay where the conceptual model of resuspension/advection fails, centred around outliers at the stations 3 and 4 (Figure 1). At stations 3 and 4 the chlorophyll-a is lower than expected and the turbidity is higher than expected (Figures 1 and 2). In other words, the amount of chlorophyll-a associated with the suspended sediment (turbidity) is less than the bay average. The reasons for this are not clear. Nevertheless, for station 3 near the water village we can speculate that the mineralisation of untreated sewage, associated with these settlements, may result in anoxic conditions. Sulphide released during anoxia can poison the microphytobenthos and their ability to stabilise sediments from erosion (Ubertini *et al.*, 2012). There is no water village associated with station 4, nevertheless the yet unknown dynamic associated with the advective plume of sediment and microalgal remains the most likely reason source of explanation.

Conclusion

Sepanggar Bay shows significant structure in the distribution of surface turbidity and chlorophyll-a as a viable microalgal population. The factor behind the distribution of the distribution is consistent with wind, wave and tidal resuspension and, in part, horizontal advection of bottom sediments, associated microphytobenthic community. The study suggests that in order to predict the formation and distribution of HABs across Sepanggar bay, both advections, depth and sedimentary sources need to be taken into account.

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