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Deployment of Wireless Sensor Network to Study Oceanography of Coral Reefs

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Abstract — **Great Barrier Reef Australia (GBR) is affected by cold water intrusions originating in the Coral Sea and upwelled on the reef. Therefore biological interest in GBR upwelling has been driven by the view that upwelled waters rich in nutrients boost plankton production and overall productivity of the GBR system. Upwelling can be a high frequency short-duration event and therefore it may be challenging to quantify synchrony between physical and biological change impacting the reef. We deployed a Wireless Sensor Network (WSN) for in situ monitoring of upwelling. Temperature is a good proxy for upwelling however 3D dense spatial data required to correctly describe upwelling and their impact on plankton abundance. The array of underwater sensors was deployed at various depths on the coral reef in Nelly Bay, Magnetic Island, GBR. The temperature data are communicated in real time via the ad hoc network using RF signal to the on-shore base station. This permits us to collect the plankton data in real time synchronized to the temperature changes. To explore the utility of WSN we also deployed dataloggers to collect temperature data from the same location. This paper outlines the methods of the WSN deployment for ecological research. It also describes preliminary results. Our preliminary findings did not produce sufficient evidence for upwelling however we did find that the water temperature can vary by as much as 1 °C even on a small spatial scale due to stratification of the water column. Stratification can influence depth-related abundance of plankton and the supply of food to reef associated organisms however we could not confirm this with statistical confidence due to the limited plankton data collected while water stratification was observed. The use of robust real time WSN to trigger plankton collection at the events of upwelling or stratification would have assisted with this investigation.**

Keywords – oceanography; plankton; wireless sensor network; stratification; tidal upwelling; temperature; coral reef

I. INTRODUCTION

Understanding the relationships between physical and biological oceanography is a challenging task due to the very dynamic nature of the oceans. This calls for the deployment of new methods and technology in oceanographic studies that allows the detection and communication of changes in real time. It was proposed to deploy a Wireless Sensor Network (WSN) to quantify the synchrony between physical and biological changes impacting the reef due to oceanic upwelling [1].

Coral reefs have incredible diversity and density of organisms and could not survive without input of additional nutrients from outside the reef [2]. Upwelling has the potential to facilitate such input and also has a great influence on the supply of planktonic food to reefs [2, 3]. Upwelling can be a high frequency short-duration event and therefore it may be challenging to quantify synchrony between physical and biological change impacting the reef. The objective of our study was to determine the influence that physical oceanography has on distribution of plankton in a coral reef environment.

In Great Barrier Reef (GBR), Australia, cold water intrusions come from the Coral Sea bringing nutrients into GBR waters [4]. Biological interest in GBR upwelling has been driven by the view that upwelled waters are rich in nutrients and contribute significantly to the overall productivity of the GBR system [4]. Moreover, Furnas and Mitchell [4] found strong correlation between temperature and concentrations of phosphate, nitrate and silicate in upwelled regions of GBR. The ocean fluctuations in nutrients result in variations in the growth of marine organisms such as phytoplankton [5-7]. Understanding the plankton abundance and composition is essential to understanding of the GBR food chain.

Plankton is considered to be one of the most important organisms on Earth since it is a primary food producer for most aquatic life. Based on the trophic level, plankton could be divided into three broad groups: phytoplankton (producer), zooplankton (consumer) and bacterioplankton (recycler) [8]. Understanding the phytoplankton productivity in the world ocean has recently become a major concern because of its role in CO2 recycling and therefore the effect on global climate change [9]. In addition to making a significant contribution in removing carbon dioxide from the atmosphere, phytoplankton creates the foundation of the ocean food chain.

The phytoplankton generally increases in biomass at the junction where frontally convergent circulation has either supplied limiting nutrients or resulted in the aggregation of plankton particles [7]. Thomson and Wolanski [10] established that strong tidal currents can pump nutrient-rich water from below the mixing layer through the reef passages onto the shelf. Such inputs of inorganic nutrients are responsible for the large fluctuations in phytoplankton biomass and overall primary production [5]. Phytoplankton blooms, defined as rapid growth in population, take place when upwelled waters bring nitrate, phosphate and silicate nutrients into euphotic zones [5]. Plankton species can move up and down the water column [11], thus plankton abundance should be estimated with respect to depth and appropriate 3D sampling design is important.

The upwelling can be caused by various dynamic processes in the ocean including wind, topography and tidal movements. Large scale coastal upwellings are generally driven by wind force. This type of upwelling occurs when alongshore winds generate Erkman transport causing the surface waters to move offshore and be replaced by deeper nutrient-rich water that upwells close to shore [12]. High frequency coastal upwelling can also be associated with tidal jets, internal tides, internal waves and internal tidal bores [13]. The temporal and spatial variability in upwelling near coral reefs may contribute to temperature variability, the balance between locally and remotely derived nutrients, and the overall dynamics of coral reef system [14].

The GBR upwelling allows the cross-shelf intrusions of Coral Sea water through the reef matrix [15]. Andrews [16] used temperature to trace cross-shelf transport which in open stratified water produces a marked bottom-temperature signal. The temperature was found to mark the upwelling intrusions adequately [16]. Furnas and Mitchell [4] found that nitrate, phosphate and silicate concentrations are strongly correlated with water temperatures.

We hypothesized that changes of sea water temperature impact the abundance of plankton and propose to set up real time monitoring of the effect of high frequency temperature changes on plankton abundance. We also hypothesize that daily tides have similar effect on plankton abundance as previously documented upwelling but with smaller magnitude.

High frequency upwelling can be created by tidal movements. Tidal currents interacting with complex reef topographies are common in coastal environments [17]. Tidal jets, tidal waves and tidal bores have predominantly cross-shore direction [18]. In coral reef environments they facilitate water exchange between the near-shore shelf, the outer shelf, the slope and the open ocean. Pineda [19] found that internal tidal bores produce upwelling by transporting subsurface water onshore and facilitating the transport of larvae. It was recorded that such upwelling was caused by tidal bores and had an effect on surface temperature that lasted days [19]. Along with the water exchange, cross-shore circulations promote exchange of nutrients, pollutants and biological material [18, 20]. The intensity of tidal upwelling and the distance they can travel shoreward is hard to predict because it is influenced by bathymetry, tidal amplitude and the passage shape thus it is unique for each area. There are very few comparable data available on shallow water upwelling close to the shore. In this study we wanted to verify if tidal upwelling in the GBR penetrates as far as 80 km shoreward and thus deliver nutrients to inshore coastal reefs.

Stratification of the water column can also create variation in biomass distribution of plankton [21]. Stratification refers to layers of different physical properties. A density barrier between the layers reduces mixing of the water. However density differences can also promote dynamic processes in the ocean. For example, even small horizontal density differences caused by differences in surface heating can create strong currents. Water density is a function of water temperature and salinity. Density increases with an increase in salinity and a decrease in temperature. Therefore waters of high temperature and low salinity generally stay at, or near, the surface and the waters of low temperature and high salinity are generally located at depth. The salinity barrier is called the halocline and the temperature barrier is called the thermocline. The thermocline and halocline can have a strong influence on the distribution and dispersal of plankton species [21, 22]. Stratification can last for hours, days and in some cases, when the water is calm, it can last for months. Stratification can be destroyed by dynamic processes promoting water mixing such as tides, storms, hurricanes, upwelling, strong winds and currents.

To be able to trace the effect of high frequency temperature changes due to daily tides, stratification events and upwelling with sufficient tolerance we propose to monitor on a relatively small spatial scale compared to previous studies. Thus the aim of this study was to understand the effect of high frequency changes in the sea water temperature due to tidal fluctuations, upwelling and water stratification on plankton distribution and abundance at Nelly Bay, Magnetic Island, Australia.

We deployed a Wireless Sensor Network (WSN) for in situ monitoring of temperature on 3D scale to be able to collect high quality spatial data required to fully understand the impact of temperature on the distribution and composition of plankton species. Data loggers have been deployed by Australian Institute of Marine Science (AIMS) for in-situ monitoring of sea temperature along various reefs of GBR. Data loggers instantaneously record sea temperatures every 30 minutes and are downloaded every 6 to 12 months, depending on the site. The data loggers store the information which can be downloaded at the end of each experiment, generally every few months, thus immediate collection of plankton samples in the event of high temperature variation was not possible. We therefore deployed WSN to allow biological data collection (plankton) at the same time as physical change (temperature) was detected.

Utilization of WSN technology is quite appropriate when dealing with very dynamic organisms such as plankton. One of the main challenges faced in plankton field studies is the fact that plankton communities are very dynamic and under favorable conditions the cells can divide quite rapidly [23]. Large short-term fluctuations in phytoplankton biomass as well as transport of matter and energy through plankton community [23] calls for a special sampling technique where sampling can be performed shortly after the potentially favorable conditions have been detected. We deployed WSN to collect 3D temperature data and communicate information about changes in the water column in real time.

II. METHODS

A. *Sensor Array*

The array of sensors was deployed on a 3D spatial scale with horizontal coordinates spaced out along the reef crest and reef flat and at various depths. Sensor network is a term used to describe the latest trend in electronic monitoring where each sensor contains a small computer able to manage and collect environmental data and transmit in real time [24]. Ambient Systems is a supplier of wireless mesh networking solutions that consist of chips embedded with the Ambient's networking software and radio transceiver technology [25]. In this study we used Ambient Systems smart temperature sensor solution based on 1-Wire devices DS18B20 from Dallas Semiconductor. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1–Wire bus; thus, it is possible to use one microprocessor to control many DS18B20s. The resolution of the temperature sensor is user-configurable to 9, 10, 11, or 12 bits, corresponding to increments of 0.5°C, 0.25°C, 0.125°C, and 0.0625°C, respectively. In this study the sensors programmed to the maximum resolution of +/-0.0625 °C.

Multiple DS18B20 sensors were connected on 1-Wire to a processing unit called Unode supplied by Ambient Systems and positioned inside the surface buoy (Fig. 1). The Unode has integrated RF networking capabilities to communicate with other Unodes and the base station thus allowing us to create a sensor network with real time data transmission capabilities. Each string of temperature sensors was connected to a Unode and positioned underwater inside of an hydraulic cable at various depths (2 meters apart) (Fig. 2). We initially deployed a network consisting of 8 moorings with one Unode each, however due to technical problems the network was downsized to 4 moorings (Fig.3).

In a sensor network, each node is able to manage the collection of environmental data. This management includes interacting with other sensors to determine the data collection rates and electronic system status. The environmental data are then packaged up using standard networking protocols to broadcast into the network. This means that if the node is unable to directly contact the target base station the data can be rerouted to the target via other sensors (ad hoc network establishment). This is very important in choppy sea conditions. There is no hierarchy between the nodes and they can be spaced out randomly to form multi-hop mesh as long as the distances are within the signal reach. The sensors communicate a unique identification number and thus the data can be tagged with three dimensional attributes (x, y and depth). The transmitting frequency band of 900 MHz was selected as the most suitable compromise between baud rate, humid environment and commercial availability of transmitters [1]. Due to corrosion of underwater cables the temperature data from WSN was only received for 16 hours on 21st and 22nd of September thus limited our analysis.

B. *Dataloggers*

To ground-truth the data we planned to receive from WSN we also used TG3100 temperature dataloggers (Gemini Data loggers UK Ltd), that were calibrated to measure temperature with ± 0.2 °C accuracy. These dataloggers are manufactured in water proof packages thus we could place them on the outside of hydraulic cables containing DS18B20 sensors. We employed TG3100 temperature dataloggers to record temperature data over time at two depth levels and different spatial position on reef profile. We placed dataloggers on four moorings out of total eight moorings used by WSN. The inner moorings were positioned on reef flat and the outer moorings on the outer edge of reef slope. Dataloggers were attached to mooring lines at two depth levels, 1m from the sea surface and 1m from the sea floor (Fig. 2). The loggers at two depth levels were expected to detect the presence of stratification or upwelling. In total, eight dataloggers were synchronized and programmed to record temperature every 10 minutes for the period from 05/09/2007 until 25/09/07.

C. *Study site*

The data on temperature and plankton were collected at Nelly Bay (146 51’ 9” E 19 9’ 52”S), Magnetic Island, Australia. Magnetic Island is situated about 7 km off Townsville; it is bordered by a number of sheltered bays with fringing reefs. Magnetic Island is classified as inner-shelf Island and is situated 7 km offshore. Nelly Bay's 1800m-wide sand and rubble intertidal reef crest and slope area was used for data collection (Fig. 3). The temperature collecting nodes were spaced out along Nelly Bay reef crest and reef flat at various depths.

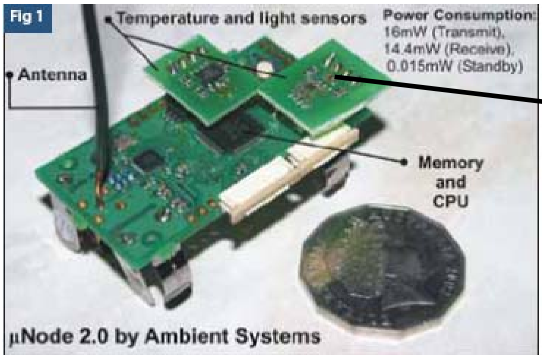


Figure 1(a): The electronic module called Unode supplied by Ambient Systems [25]. The Unode incorporates radio transmitter, receiver and a memory card.

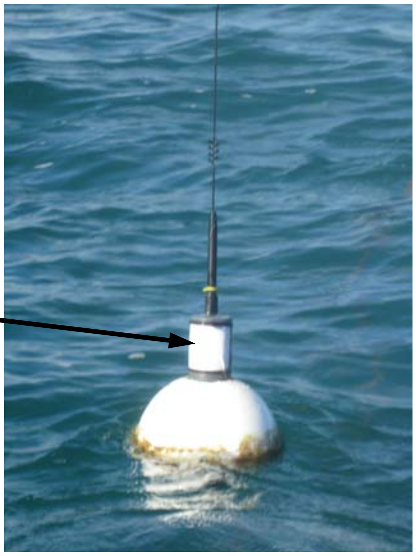


Figure 1(b): Photograph of the surface buoy with Unode placed inside the plastic canister with external antennae. The black arrow points Unode position inside the surface buoy.

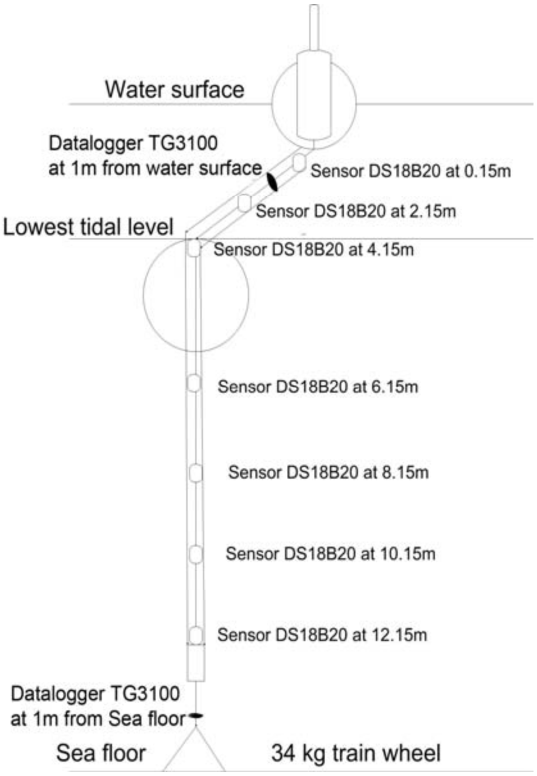
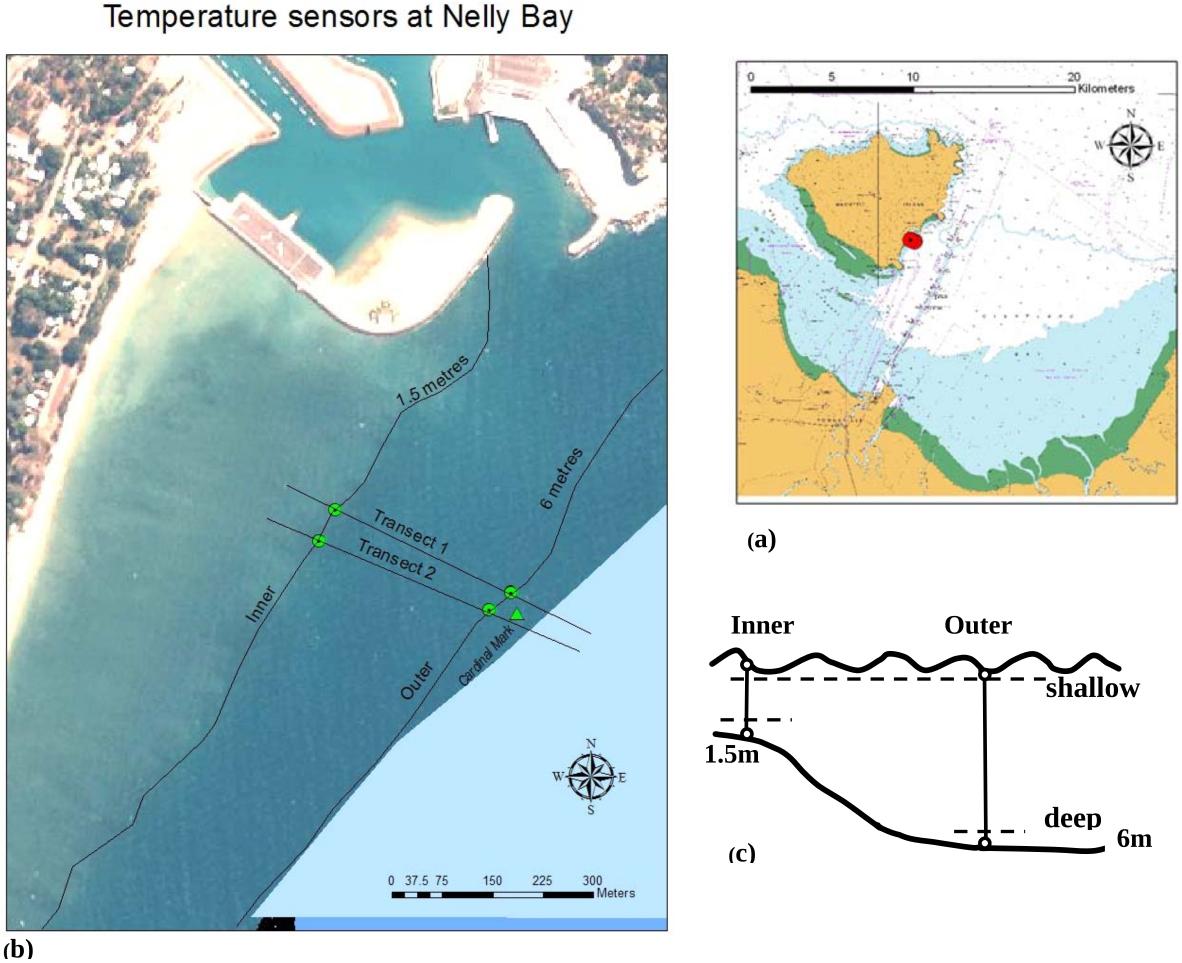


Figure 2 (a): Diagram of the sensor mooring with seven DS18B20 digital thermistors and two data loggers TG3100.

Figure 2 (b): Underwater photograph of the inner mooring with temperature sensors inside the hydraulic cable. Visible in this photograph is the sub-surface float and the wagon wheel anchor. The cable connecting sub-surface float to the surface buoy is floating loose to allow tidal variations.


Temperature sensors at Nelly Bay

(a)

(b)

(c)

Figure 3: a) Magnetic Island and Nelly Bay b) Study site at Nelly Bay, Magnetic Island, Australia. The sensor network consisted of two transects with two moorings each. Each moorings had seven temperature sensors deployed on vertical scale 2 meters apart (Fig. 2). The inner moorings of each transect were placed on the reef flat at 1.5 meters depth (lowest astrological tide) and the outer moorings were placed on the outer edge of the reef slope at 6 meters depth; c) schematic representation of transects with inner and outer moorings in respect to reef bathymetry on vertical scale, dotted line indicates depth strata (shallow and deep).

D. Temperature stratification and upwelling

We expected to detect both water stratification and upwelling during observation period. The intrusion of cool water to coastal areas often varies with lunar tides [13]. It was predicted therefore that stratification and upwelling would be greatest during spring tides. To separate these events from the temperature offset caused by calibration and resolution of DS18B20 sensors and TG3100 dataloggers a threshold had to be established. When comparing data from 2 dataloggers (shallow and deep) the maximum error rate would be 0.4 °C net based on the accuracy of TG3100. This level of error would be very unusual. A criterion of 0.5°C net vertical gradient from the surface temperature was recommended as a threshold to distinguish weakly stratified regions from unstratified [26]. We therefore adopted this criterion (0.5°C as maximum difference between shallow and deep temperatures, ΔT) for the water column to be considered mixed. Thus stratification or upwelling would be detected if ΔT≥0.5 ºC.

We expected to be able to detect upwelling as cold water intrusions moving vertically up and horizontally towards the shore and finally reaching the surface. It was predicted that the outer mooring sensors would detect temperature drops first and then cold water intrusions would reach inner moorings but with some time delays.

We initially intended to spatially analyze the stratification and upwelling events based on the temperature data from 8 mooring stations. However due to technical problems the data were downloaded from 4 stations only thus limiting our capacity to do spatial analysis with statistical confidence.

E. Plankton data collection

To measure the influence of water temperature on plankton abundance, depth stratified plankton samples were collected next to each temperature station. We expected that depth related patterns would be greatest at spring tides and therefore plankton samples were collected on a high tide during spring tides using Niskin bottles. Niskin bottles are in common use for small size plankton sampling; they are cylinders that can remove columns of water of known diameter and depth [27]. The Niskin bottle method was preferred for this study over collection with plankton net because it minimizes trauma and enhances the survival of phytoplankton taxa that are easily damaged or killed when they come into contact with the mesh of plankton net [28]. This method also allowed us to take samples precisely next to each temperature station which would not be possible with long tows of plankton nets. In this study we used 5-litre Niskin bottles. The water samples were collected next to each temperature station at two depth levels that correspond with the depth of temperature loggers (1 meter from the sea surface and 1m from the sea floor). We collected plankton samples at the time of high tide during spring tides (high tide of ≥ 3.4 meters). In total we collected 40 samples over 5 days from 6th to 11th of September 2007.

The water bottle adequately sampled mesoplankton (0.2 - 2 mm) and microplankton (20-200 μm). A 50 μm mesh sieve was used to concentrate 5-litre field samples into 250 ml jars. All samples were concentrated and preserved in 3% formalin within three hours from collection to avoid predation or decomposition.

F. Laboratory techniques

In the laboratory facilities samples were further filtered using 50 μm mesh sieve to a 20 ml concentrate out of which 1ml subsamples were taken. We used a modified 10 ml calibrated pipette with wide mouth (5mm) to provide wider entrance for the small organisms [28]. The 20 ml concentrate was stirred prior to taking a subsample. Manual mixing was not sufficient to mix up and break up colonial phytoplankton. Phytoplankton species which aggregated in colonies or chains were excluded from counts due to higher effect of patchiness on subsample variance. Thus only unicellular unchained species were counted and analyzed. We used Sedgewick grid which contains 1ml of subsample volume for plankton counting.

III. RESULTS

A. Temperature variations and physical oceanography

The water column was generally homogeneous in September 2007 however a vertical stratification was found on some occasions at both transects (Fig. 4). The average difference between shallow and deep dataloggers was 0.1 ºC which indicated that the entire study area was a mixed layer. Stratification events occurred during spring and neap tides and were most obvious at the outer sites (Fig. 4). In contrast, the waters were well mixed at the inner sites. The maximum temperature difference between surface and near the substratum loggers was 1.2 ºC (1pm on 6th of September, Fig. 4b). A 1 ºC difference on 17th of September ranked second and occurred around 4pm (Fig. 4b). The first stratification event lasted for 2 hours (12pm-2pm) and the second event on 17th of September lasted for 8 hours (11am-7pm) calculation based on critical criterion of $\Delta T \geq 0.5$ ºC.

The first stratification event occurred during spring tides (maximum amplitude of 2.7 meters) and the second event occurred during extreme neap tides (amplitude of 0.8 meters, Fig. 4). Tide amplitude therefore was not the main factor driving temperature stratification as originally predicted. This was confirmed by regression analysis that showed no relationship between the tide amplitude and stratification level represented as the difference between temperatures of shallow and deep layers of the water column ($r^2 = 0.0035$; ANOVA F=0.267; df=1,78; ns).

The data also showed that extreme spring tides (amplitude of around 3 meters) did not promote mixing of the water column more or less than tides of lower amplitude. Greatest stratification did not occur at any particular phase of the tide. On some occasions stratification was greatest at low tide and others at high tide but only during neap tides (Fig. 4). Peak periods of stratification were during tides of low amplitude and near low water at other times (Fig. 4).

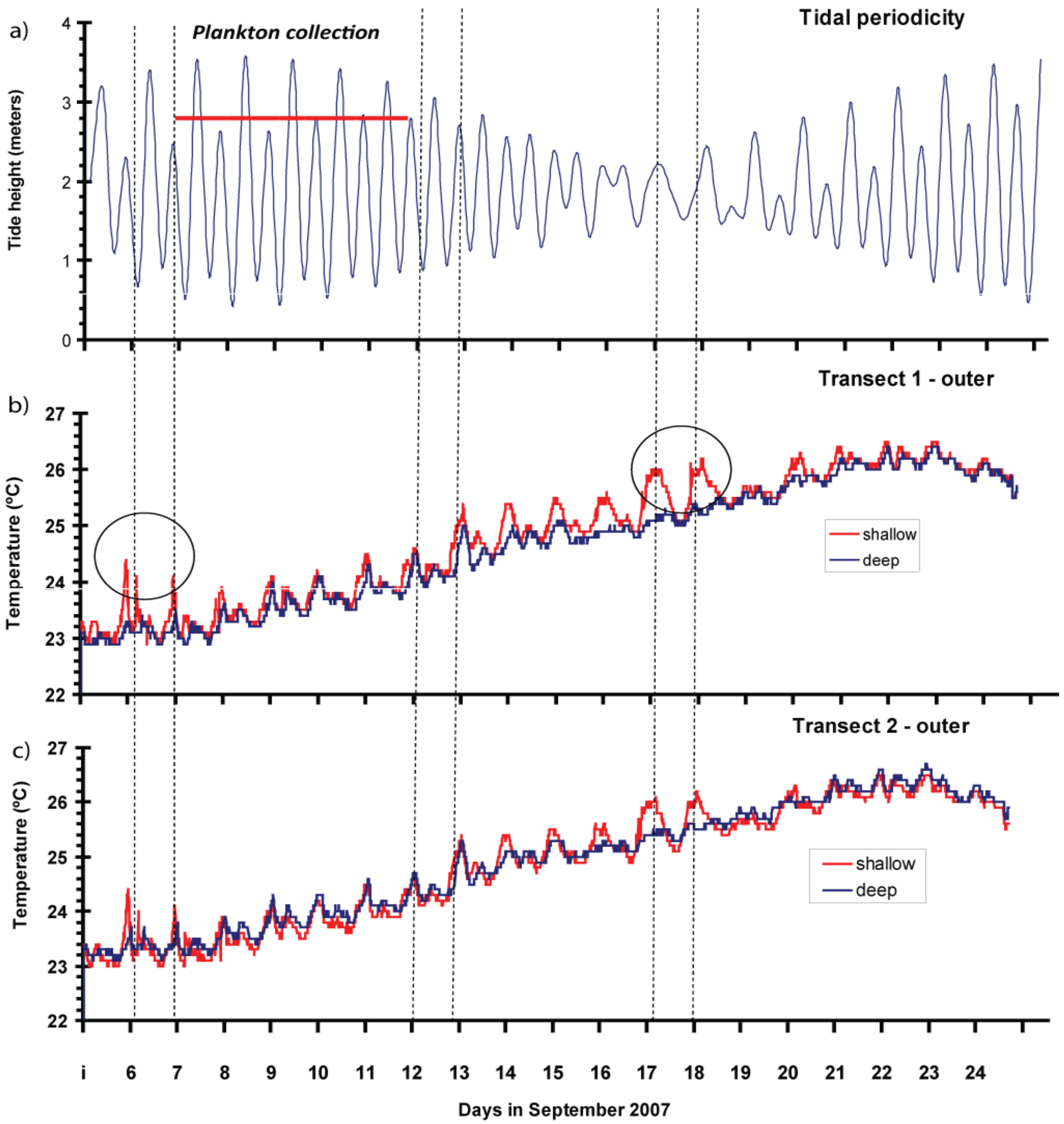


Figure 4: a) Tidal variation during 20 day period in September 2007, the red line highlights the spring tides and when plankton was collected. b) and c) Temperatures at shallow (1m from the surface) and deep (1m above the sea floor) dataloggers from transect 1(b) and transect 2(c) recorded at the outer moorings (Fig. 3). Circles in figure (b) highlight the events of water stratification. The dotted lines show the tidal phases during daily temperature peaks and falls on 6, 12 and 17 of September.

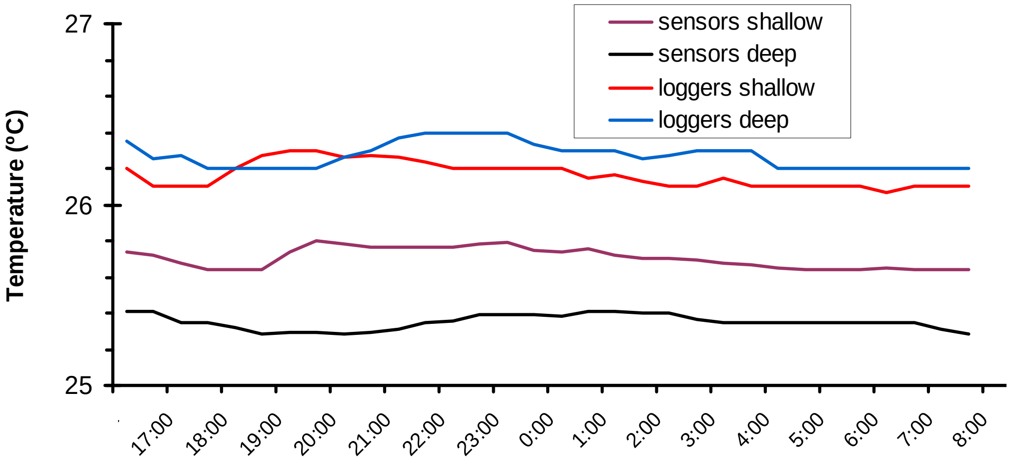


Figure 5: Temperature data collected by the data loggers (TG3100) and real time sensors (DS18B20) at the outer mooring station of transect 2 on 21st and 22nd of September 2007. The data loggers and real time sensors were fixed on the same mooring line at two depth levels: shallow (within 1 meter from the surface) and deep (1 meter from the sea floor).

No upwelling was detected during the observation period. Despite thermal stratification the cold water did not persist at the surface. The daily temperature drops of 0.8 ºC on average did not always correlate with phase of the tide (Fig. 4). Moreover, high temperature variations between daily maximum and minimum occurred during spring tides (maximum difference of 1.3 ºC, Fig. 4) and during neap tides (maximum difference of 1.1 ºC, Fig. 4). Tidal amplitudes did not correlate to daily temperature variations ($r^2 = 0.0049$; df=1, 20; ns). Thus bigger tides did not produce greater differences between daily temperature maximum (peaks) and daily temperature minimum (drops).

B. *Real time sensor array*

The utility of a real time sensor array based on WSN technology was tested and ground- truthed with dataloggers. We compared the temperature data measured by dataloggers and real time sensors on the same spatial and temporal scale (Fig. 5). Both datasets showed the same trends, however there was a temperature offset between real time sensors and dataloggers of approximately 0.5 ºC (Fig. 5). This was due to the accuracy of temperature data received from DS18B20 sensors.

C. *Plankton abundance*

The relationships between plankton abundance and depth varied daily for most taxa. When differences were found it was generally at day one of the plankton collection (6th of Sept) when the water column was stratified by 1.2 ºC difference between shallow and deep loggers. Differences in abundance between depths were found at day one for nauplius larvae, diatom *Coscinodiscus* spp. and the dinoflagellate *Ceratium* spp. Abundance of nauplius was high in shallow waters during day one and changes in rank abundance among days resulted in a significant interaction between day and depth. Abundance of copepods varied among days with highest numbers of copepods collected at the last two days of collection period. Although there was a trend for difference of copepod abundance between depths on day two and five this was not detected by ANOVA. Main effects and interactions were not detected for other taxa probably due to high residual variants.

IV. DISCUSSION

A. *Temperature stratification*

Although we did not find sufficient evidence for upwelling this study confirmed initial prediction that the water temperature can vary significantly even on a very small spatial scale; thus adequate spatial resolution is required when collecting temperature data to analyse oceanographic events on coral reefs.

This study challenges the existing view that the inner shelf waters of the GBR Lagoon are generally unstratified [16, 29-31]. Wolanski et al. [30] measured the temperature across the GBR Lagoon offshore from Townsville and found that there were no vertical temperature gradients for inshore waters and some were found offshore during calm weather conditions. Wolanski et. al's [30] measurements were taken weekly from Jan 1979 to Jan 1980 over a large spatial scale. Similar observations were documented by Orr [32] in September-October 1933 in the GBR Lagoon close to Low Isles (station at 16.35ºS, 145.6ºE) in 32 meters of water where they found less than 0.1ºC gradient between surface and deep waters. Similar to Wolanski et al. (1981) Orr recorded temperature on a weekly basis [32]. Our study was different to previous studies of the GBR Lagoon both spatially and temporally. Stratification events that we found in Nelly Bay were short duration events lasting less than one day. For most of the observation period the waters in Nelly Bay were well mixed (less than 0.1ºC vertical gradient) and thus if the temperature was recorded weekly the stratification events most probably would not be reflected in the collected temperature data. The important implication of this study is that sea surface temperature (SST) data alone may not be reflecting the full complexity of oceanographic processes within lagoon.

B. Influence of stratification on plankton distribution

Thermal stratification of the water column influenced the distribution of some planktonic taxa. Stratification often affects the distribution of phytoplankton [33]. In this study there were strong trends for nauplius larvae, *Coscinodiscus* spp. and *Ceratium* spp. to be more abundant in shallow waters when the water column was stratified. Vertical differences in abundance were most obvious in nauplius larvae and *Coscinodiscus* spp, both of which were more abundant in shallow waters during stratification.

C. Utilization of real time WSN for oceanographic studies

The ability to explore the relationship between stratification and distribution of plankton is often hampered by a lack of real time data. We demonstrated that utilization of WSN can provide real time communication of temperature data about oceanographic events and consequently biological sampling can be planned to address specific hypotheses. For example, timely information about stratification events would facilitate exploration of the biological effect that physical oceanography has on plankton. Unfortunately due to technical problems with WSN we did not receive real time data about the second stratification event on 17th of September and thus plankton samples were not collected during this event. This limited our ability to do comparative analysis of plankton abundance during thermal stratification but at the same time highlighted the advantages that WSN technology can offer for plankton studies.

WSN offers several advantages over historical monitoring techniques by streamlining the data collection process, potentially minimizing human errors and time delays, reducing overall cost of data collection, and significantly increasing the quantity and quality of data both temporally and spatially [34]. Wireless sensor networks allow fine grained interface between the virtual and physical worlds and thus represent the future for environmental monitoring [35]. Future studies would be able to utilize wireless sensor network to trigger plankton collection once the water temperature anomalies were detected. The design of the system has to be more robust to be able to survive in the aggressive sea water environment [36] and temperature sensors would have to be calibrated to industry standards prior to deployment.

V. CONCLUSION

This study demonstrated that short term stratification can occur in shallow tropical waters and influence the distribution of plankton. This challenges the traditional view that waters of the GBR Lagoon are always well mixed and that surface values of temperature and salinity are representative of the whole water column. Stratification was caused by cooling in shallow water at night. Greatest warming in shallow water happened during low tides and at low tide amplitude phases of the lunar cycle. The ability to observe changes in phytoplankton production at the time or shortly after physical changes in the water column is crucial to furthering understanding of the trophic dynamics of marine ecosystems. The current study highlights the utility of real time WSN as a means of achieving this goal.

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