A Real Time Measurement System for Red Tide Studies

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Abstract - **An apparently increasing trend of red tide occurrences and/or harmful algal blooms has become a global issue, particularly in coastal zones with 'cultural eutrophication', but no effective measures have been developed yet for detection and early warning, in order to prevent public health problems and the threat of economic losses. A multiple-probe-and-sensor based telemetry system has been developed to monitor water quality parameters, hydrographic variables and meteorological conditions, in order to provide almost real time and continuous data for red tide studies. Several red tides have been detected with the system during the study period and this suggests that it potentially fulfills the purposes of detection and early warning. However, there is still room to improve, upgrade and develop further this prototype system to apply it widely to coastal regions, particularly fish culture zones in which red tides occur frequently and intensively. Real-time telemetric data can provide background information concerning red tide formation conditions, and can be extended to bio-ecological studies so as to enhance our understanding of the interactions between red tides and marine microalgal dynamics, by overcoming the limitations of the traditional approaches.**

I. INTRODUCTION

Discolouration of sea water caused by rapid growth of marine microalgae is called a red tide (or by the more contemporary term 'harmful algal bloom'). Strictly speaking, it is a completely natural phenomenon, but an apparently increasing trend of red tide occurrences and/or harmful algal blooms has become a global issue, particularly in coastal zones with 'cultural eutrophication' from domestic, industrial and agricultural wastes [1]. Some marine algal species can produce potent toxins which accumulate in shellfish and pass through the food web to cause poisoning of human consumers, others can cause fish kills. Blooming due to the former species can lead to public health threats and to economic loss. However, no effective measures have been developed yet for detection and early warning (either in the short-term, a few days, or the long-term, seasons and years), in order to prevent such public health problems and the threat of economic losses. In 1998, a month-long red tide occurred in Hong Kong which wiped out 1,500 tonnes of fish stock worth over HK$200 million (US$25.8 million), as reported by the press [2]. From 1980 to 1999, 571 incidents of red tides have been recorded in Hong Kong waters [3]. However, the reasons for the formation of these red tides are not yet clear although it is believed that they could be subject to different factors under different environmental conditions. In order to understand the formation mechanism and ultimately to achieve a reliable detection for red tides so as to provide an early warning to the public, a multiple-probe-and-sensor based telemetry system has been adopted by an interdisciplinary research team at The University of Hong Kong to monitor water quality parameters, hydrographic variables and meteorological conditions, in order to provide almost real time and continuous data for red tide studies. This paper sets out to analyze, summarize and discuss the data collected during one of several red tides detected with the system within the study period.

II. MATERIALS AND METHODS

Telemetry is a system consisting of several probes and sensors to monitor and measure multi-parameters. The main components of the system are a YSI membrane type DO probe connected to a YSI 58 DO meter; a R. M. Young propeller-vane type anemometer; YSI thermistors for surface, middle and bottom measurements (water depths of 1m, 3m and 5m below surface water level respectively); a Sontek acoustic doppler current meter; a pumping system and relay box; a data micrologger; a 12v car battery to supply power to the micrologger and thermistor channels; and a Chelsea Minitracka II miniature fluorimeter equipped with a flow-through cell. The whole system was deployed on an operating fish raft in a field research station located within a fish culture zone in a semi-enclosed bay, namely Mun Tsai Wan, of Crooked Island (Kat O Chau) (Figure 1) in the northeast of Hong Kong waters [4].

The primary parameters used as indicators for water quality monitoring and algal biomass estimation and measurement were dissolved oxygen (DO) and chlorophyll *a* (Chl-*a*), and readings of both were taken automatically every two hours from each water depth. All data, together with readings of other parameters, were logged in the micrologger and could be retrieved through modems, one of which was connected to a computer in the campus laboratory and the other to a micrologger at the field research station. Details of configuration, functioning and operation of the system have been provided previously [4] and [5]. A 24-hour *in situ* field observation was conducted on 22nd and 23rd March 2001 during a red tide outbreak indicated by the telemetry system's increasing Chl-*a* readings. Phytoplankton samples were collected from each water depth at four hour intervals; concentrated with a special hand-made tube-shaped sieve of mesh size 20 microns; and preserved with Lugol's solution for cell enumeration and species identification. Reference [6] provides details of the sampling procedure, and taxonomic studies of the species.

III. DATA ANALYSIS AND RESULTS

A. Data analysis

A set of telemetric data for the red tide detected on 22nd and 23rd March 2001 is shown in Figures 2.1 to 2.5, which cover the period 18th to 28th March 2001, and include Chl-*a*, DO, solar radiation, water temperature, and wind speed and direction. Details of field data for temporal and spatial variations of marine microalgal abundance in the red tide and the corresponding DO and Chl-*a*, water temperature, salinity and pH are shown in Figures 3 and 4 respectively. For convenience of analysis, the first set of field data were from water samples taken at 09:00 on 22nd to study marine microalgal species were treated as taken at 08:00. Data for pH and salinity were measured manually *in situ* with YSI 85 DO meter, whereas DO, Chl-*a* and water temperature were retrieved from the telemetric database. Each time interval in Figures 3 and 4 contains three individual sets of data representing three water depths, indicated with arrows labelled as 1m, 3m and 5m respectively.

B. Results

A Chl-*a* peak is shown at 16:00 on 22nd March 2001 in Figure 4 with a reading of 17.2ìgL^{-1}. The reading exceeded 15ìgL^{-1}, which is a threshold value for Chl-*a* set by the research team to determine a red tide. The red tide detected occurred in the middle water layer, e.g. 3m below the water surface. The peak can also be found in Figure 2.1 (indicated with an arrow). The causative organism for the red tide was *Gonyaulax polygramma* Stein (Dinophyceae), together with four other species, *Leptocylindrus danicus* Cleve, *Cerataulina pelagica* (Cleve) Hendy, *Pseudo-nitzschia pungens* and *Skeletonema costatum* (Grunow ex Cleve) Hasle. The five species accounted for more than 63.5% of the total cell number per liter in each water sample. Twenty eight genera (including 48 species) were recorded from the water samples. *G. polygramma* numbers were 6.19×10^3 cellsL^{-1} and 25.95% of the total sample number. Although the cell numbers of *G. polygramma* were less than *L. danicus*, the cell size of *G. polygramma* is much larger (35-66ìm in length and 26-56ìm in width) than *L. danicus*, which has valves 6-12ìm in diameter and height 2-10 times as much [7]. During the red tide outbreak, salinity was almost constant at 31.4-6ppt and pH ranged from 7-8. The temperature difference for all depths was about 2.2^{0}C (ranging from 19.5 to 22.7). DO was maintained in the range of 7.5 to 9.5 for all depths except the red tide reading, which was higher than the others (Figure 4). Chl-*a* and DO readings for 12:00 on 22nd were missed due to an instrument fault. Cell numbers of the five species showed no regular pattern (Figure 3) but were almost of the same amplitude for all depths within the same time interval.

IV. DISCUSSION

A. Blooming

Preceding the red tide detected and observed in the field on 22nd and 23rd March 2001, three peaks were recorded on 18th and 19th (Figure 2.1). It was for this reason that the 24-hour observation was conducted in order to catch the next bloom, if any. It suggested that there would be a first bloom on the 19th and, indeed, Chl-*a* readings in the middle and bottom layers exceeded 15ìg/L. After the 19th, the bloom decayed but a second bloom was generated on the 20th and emerged on the 21st. This showed a very similar pattern to the other bloom and occurred in the same water layers, middle and bottom. There was a 'short break' from blooming on the 21st. The third bloom, i.e. the one under discussion, occurred on the 22nd in the middle layer. Water samples were collected at 09:00 on 22nd with a four-hour sampling interval thereafter. The results are plotted in Figures 3 and 4. All three blooms shared a similar pattern and occurred in the middle and bottom layers, although the bottom layer on the 22nd did not exceed the threshold value. However, the trend was very similar for the three blooms, blooming in the middle layer was stronger than at the bottom. As the trends and patterns were very similar for all three blooms, the causative organism could be inferred to be *G. polygramma*. According to the official weekly report, the bloom on 22nd still persisted on 23rd [8]. After that date, many more peaks are still obvious in Figure 2.1 but these are beyond the scope of this paper.

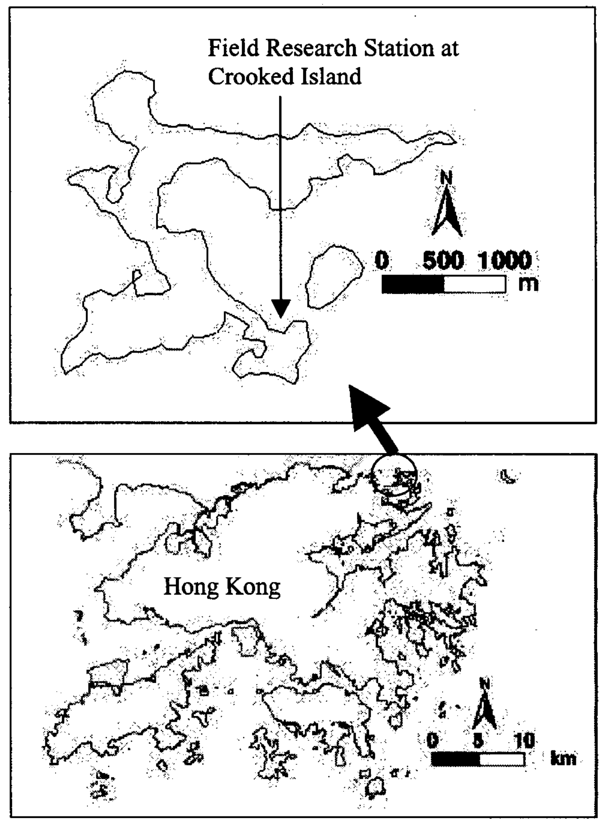

Fig. 1. Outline of Hong Kong and the location of the Crooked Island field research station

B. Red tide formation

Algal growth [9] may be directly subject to the influences of various factors such as temperature, oxygen supply, light and salinity. Eutrophication of coastal waters, phosphate release from sediments, nutrient circulation in the surf zone, stratification, change of direction of periodic winds, grazing pressure depletion, etc. have been comprehensively discussed in relation to the formation of red tides [10]. Climatological conditions such as El Nino have also been considered [11]. Studies in the Hong Kong context showed that subtropical red tides are limited by several factors including nutrient supply and environmental conditions [12]. The telemetry provided real-time and continuous data for many different meteorological parameters, e.g. wind speed and direction, solar radiation as well as air temperature, which are useful for understanding the conditions preceding the formation of a red tide. Such data could overcome the limitations of traditional approaches. During this red tide, almost none of the physical parameters showed significant variation, other than solar radiation (Figure 2.3). Although the quantity of solar radiation on 18th to 21st was lower than on later days, blooming still occurred. Because of the lack of real time data for nutrient conditions and phytoplankton abundance and contents, the data were not suitable for statistical analysis to establish the possible correlation or investigate dominant formation factors further.

C. *Marine microalgal dynamics*

The causative organism for this red tide, *G. polygramma*, is one of eight species which frequently cause red tides in Hong Kong waters. Up to 1999, there had been 46 incidents recorded due to *G. polygramma* and it caused two incidents of fish kills in 1988 [3]. Although the bloom appeared in the middle level, it was observed *in situ* that nearby water was discoloured to a dark reddish-brown colour and this seemed to persist for more than three or four days for successive blooms after the 23rd, since several peaks could be observed in Figure 2.1. Such persisting blooming was similar to that observed in 1988 when a three-month red tide caused by *G. polygramma* occurred in Hong Kong's Tolo Harbour [13]. Literature recorded that, in 1988, the DO remained within the normal range, i.e. higher at the surface but lower at the bottom during the bloom [13], which was different from the current case in which DO showed no significant change in the whole water column, except in the surface and middle layers at 12:00 on 22nd. However, it has been reported that *G. polygramma* red tides in Japan and South Africa were associated with fish and shellfish kills due to low oxygen content of the water [14]. It was suggested that *G. polygramma* possibly existed in the surface layer in the daytime and migrated to the bottom in the night time [15]. In the current case, cell abundance of *G. polygramma* showed a similar pattern, but most cells stayed in the middle and surface layers (except that they accumulated at the bottom at 16:00, 22nd) during daytime, but only a few of the cells remained at the surface at night when the cell abundance of *G. polygramma* was higher at the bottom (Figure 3). Although the red tide was probably mainly caused by *G. polygramma*, other species might contribute to red tide formation. As outlined above, different species may possess different cell sizes, which would affect their Chl-*a* content and the intensity of the feedback signal due to fluorescence responding to light emitted from the fluorometer. No clear pattern in species abundance could be observed in terms of inter-specific interaction or succession, although temporal and spatial variations of cell abundance were observed. Increases in cell numbers are not necessarily related to increases in Chl-*a* or DO readings. This lack of any clear pattern in inter-specific dynamics made it difficult to understand the formation and conditions necessary for the formation of a red tide since the relationships amongst the species are unknown.

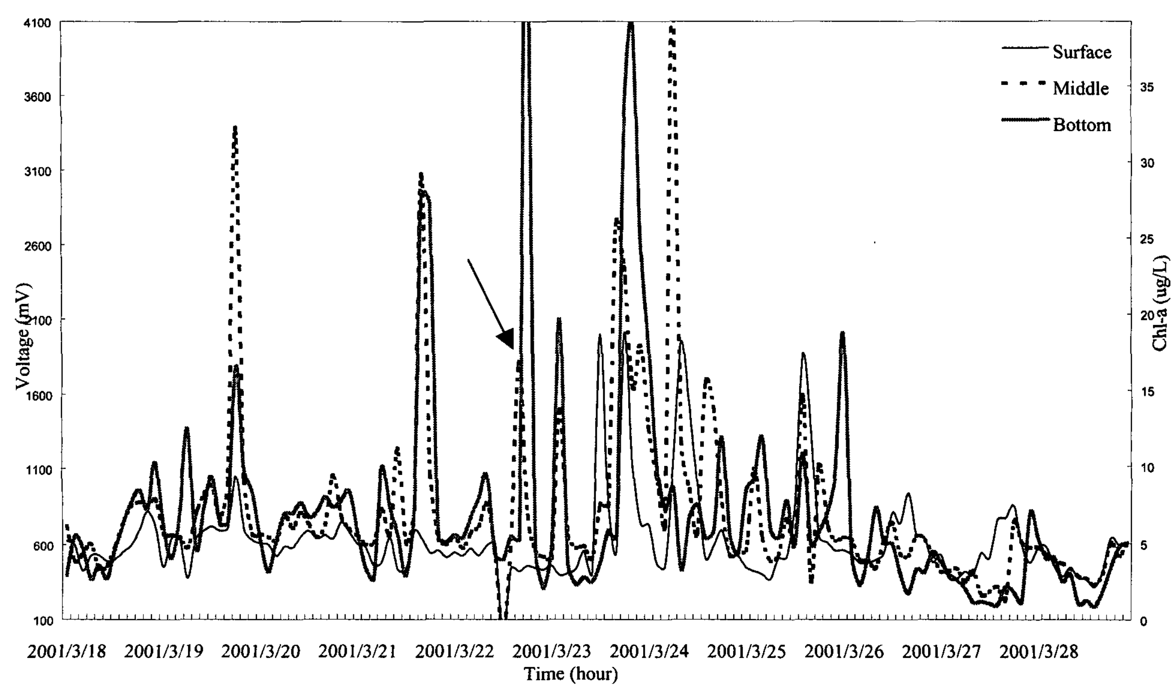

Fig. 2.1. Telemetric data for temporal and spatial variation of Chl-*a*

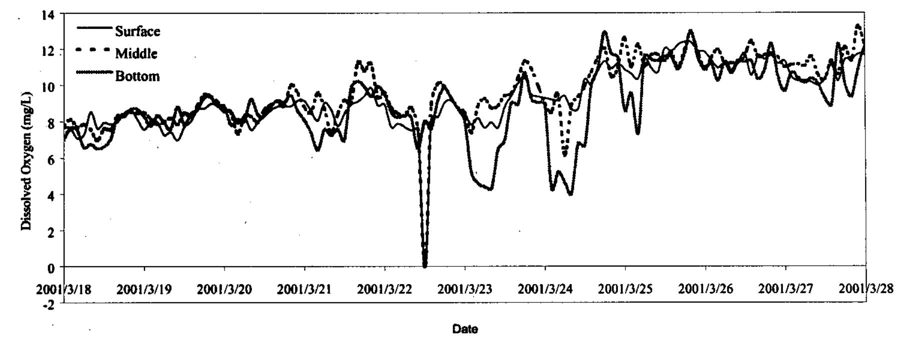

Fig. 2.2. Telemetric data for temporal and spatial variation of DO

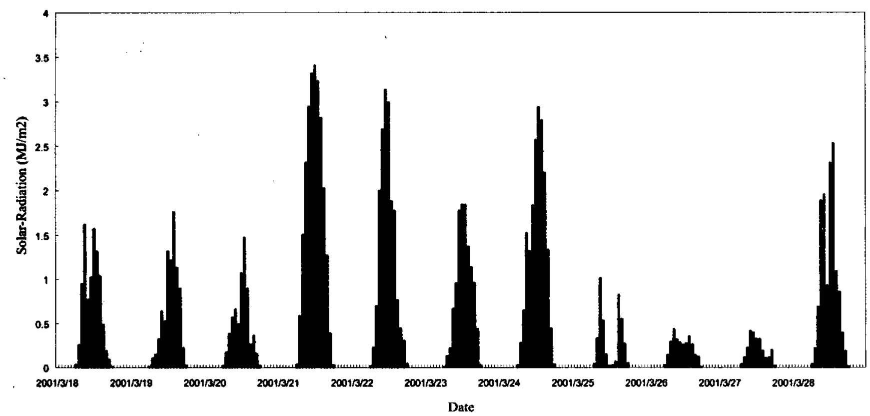

Fig. 2.3. Telemetric data for temporal and spatial variation of solar radiation

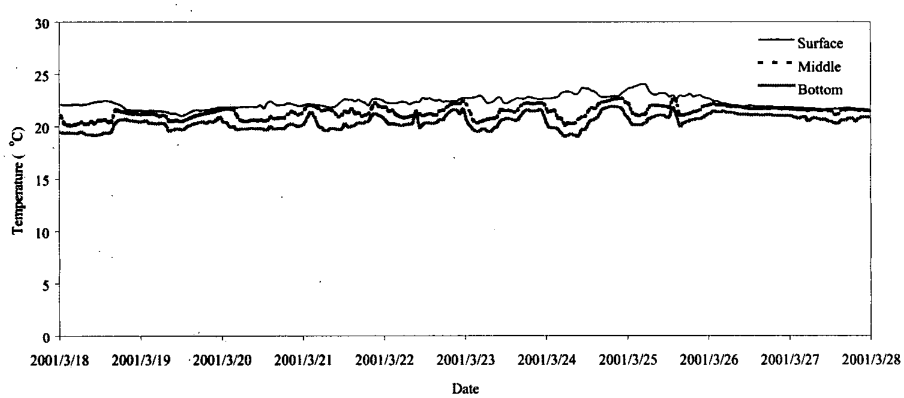

Fig. 2.4. Telemetric data for temporal and spatial variation of temperature

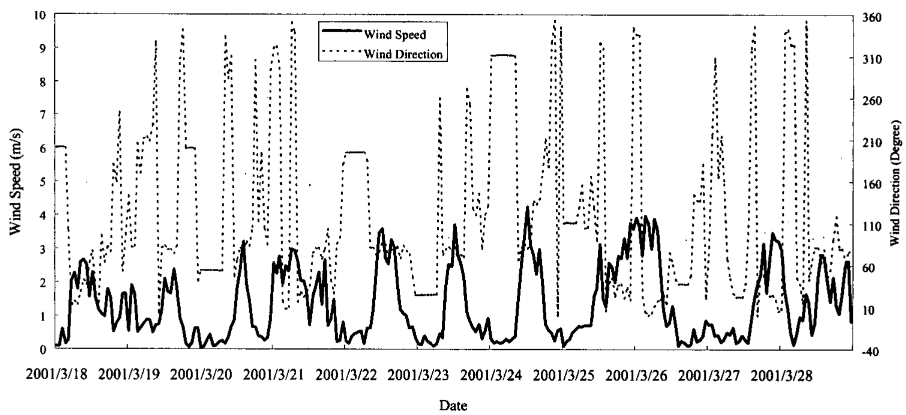

Fig. 2.5. Telemetric data for temporal and spatial variation of wind speed and direction

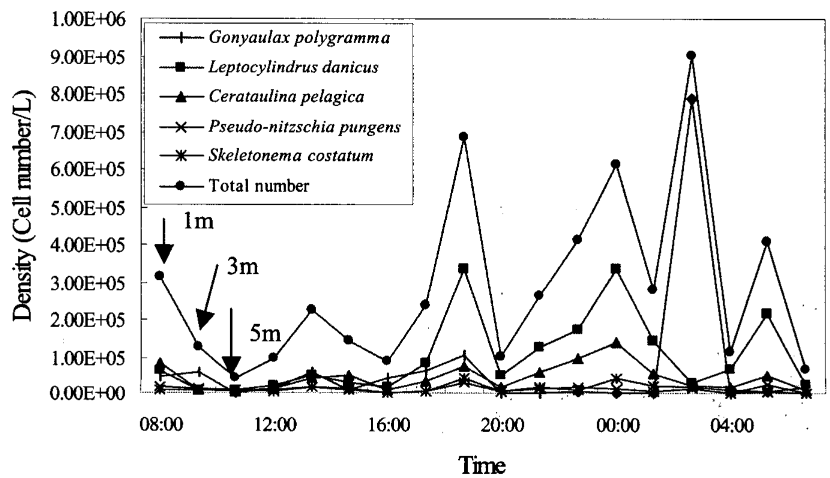

Fig. 3. Temporal and spatial variation of species abundance

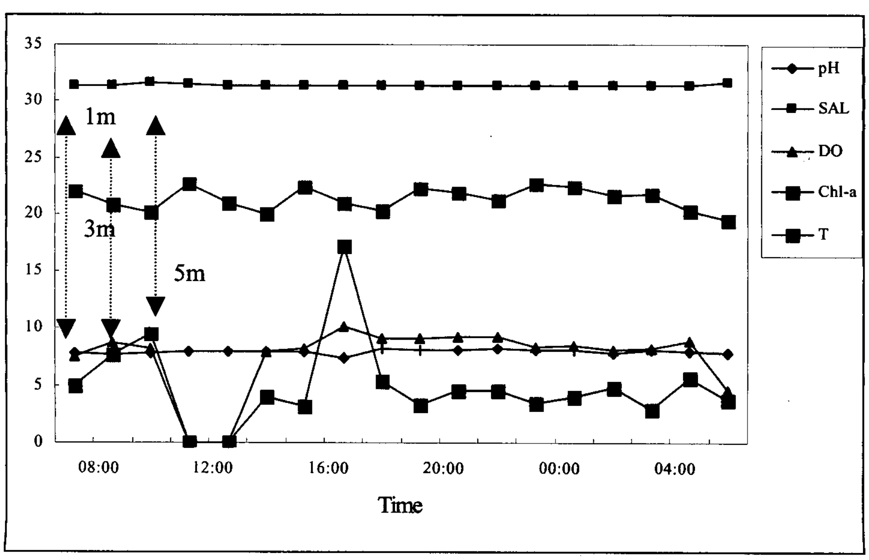

Fig. 4. Temporal and spatial variation of pH, SAL: Salinity (ppt), DO (mg/L), Ch-*a* (ìg/L) and T: Temperature (^{0}C)

D. *Feasibility of widely applying telemetry system*

Application of telemetry to monitor water quality and algal biomass in terms of DO and Chl-*a* was successful in detecting several red tide events at the Crooked Island field research station. A summary is given in Table 1. It suggests that the system potentially fulfills the purposes of detection and short-term early warning. Real-time telemetric data can provide background information concerning red tide formation conditions, and can be extended to bio-ecological studies so as to enhance the understanding of the interactions between red tides and marine microalgal dynamics, by overcoming the limitations posed by the traditional approaches. In addition, the data could also be used for model simulation for prediction purposes. However, there is still room to improve, upgrade and develop further this prototype system to apply it widely to coastal regions, particularly fish culture zones in which red tides occur frequently and intensively. One of the important improvements needed is real time data for nutrients, in addition to the need of a profiler for pH, photosynthetically active radiation, rainfall and phytoplankton samples in a real time mode for establishing any possible correlation between the dynamics of marine microalgae in response to environmental conditions. Also, safety measures are needed to ensure the instruments are functioning well and that the data generated are reliable. Microwave transmission of telemetric data could be considered to avoid telephone disruption. Furthermore, sensitive calibration of the fluorometer and DO meter must be given more attention because of the diversity of species with various strengths of response in terms of their fluorescence characteristics [6].

TABLE I
Occurrence of red tide detected through telemetry and/or water discoloration

Date	Dominant Species	Detected by Telemetry System	Detected by Discoloration
28 Dec. 1999 – 1 Jan. 2000	*Mesodinium rubrum*	No - due to equipment failure	Yes
19 Feb. 2000 – 21 Feb. 2000	*Mixed species*	Yes	Yes
16 Mar. 2000 – 17 Mar. 2000	*Gymnodinium sanguineum*	Yes	No
3 May 2000 – 8 May 2000	*Prorocentrum sigmoides*	Yes	Yes
18 Aug. 2000	*Hermesinum adriaticum*	No good indication of algal blooming	Yes
1 Oct. 2000 – 4 Oct. 2000	*Scrippsiella trochoidea*	Yes	Yes

V. CONCLUSIONS

Red tide is a millennium as well as a global problem. It is not easy to understand red tide formation mechanisms because the different causative species may be subject to different individual factors or under the synergistic effect of multiple factors, thus complicating the problem [6]. Most red tides are visible but subsurface blooming is not easily observed unless there is an effective monitoring system. Although there are still many faults which need to be improved, telemetry provides a way forward worthy of consideration. Up to now, results from the application of telemetry for detecting red tide shows the system has a high potential use, but it may depend on the background information available on red tide causative organisms, species diversity and composition, as well as the characteristics of blooming due to specific species, for example, *Noctiluca scintillans* in Hong Kong, *Cochlodinium polykrikoides* in Korea [16] and *Chattonella antiqua* in Japan [17]. Furthermore, the data collected through telemetry would be useful for ecologists to study marine microalgal dynamics as well as being invaluable to researchers who are interested in studying red tide.

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