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A continuous, real-time water quality monitoring system for the coral reef ecosystems of Nanwan Bay, Southern Taiwan

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ABSTRACT

The coral reef ecosystems of Nanwan Bay, Southern Taiwan are undergoing degradation due to anthropogenic impacts, and as such have resulted in a decline in coral cover. As a first step in preventing the continual degradation of these coral reef environments, it is important to understand how changes in water quality affect these ecosystems on a fine-tuned timescale. To this end, a real-time water quality monitoring system was implemented in Nanwan Bay in 2010. We found that natural events, such as cold water intrusion due to upwelling, tended to elicit temporal shifts in coral spawning between 2010 and 2011. In addition, Degree Heating Weeks (DHWs), a commonly utilized predictor of coral bleaching, were 0.92 and 0.59 in summer 2010 and 2011, respectively. Though this quantity of DHW was below the presumed stress-inducing value for these reefs, a rise in DHWs in the future may stress the resident corals.

1. Introduction

Nanwan Bay, which is within Kenting National Park (KNP), is located at the southernmost tip of Taiwan and supports one of the most highly biodiverse marine ecosystems in Taiwan, likely as a result of its highly dynamic water flow regime from its physical connection to the Luzon Strait (Lee et al., 1999a,b). The scenic landscape of Nanwan Bay has led to an explosion in ecotourism, which, unfortunately, threatens the ecological integrity of this unique environment. Specifically, in response to the rapid expansion of tourism, farmland destruction has increased along the Kenting coast to accommodate large construction projects, such as hotels. Furthermore, increasing tourist numbers threaten to place an excessive anthropogenic burden on the natural environment via increased coastal development, fisheries activities, sewage and other pollutant discharge, and consequent eutrophication (Meng et al., 2007a,b, 2008; Liu et al., 2012).

The KNP coral reef ecosystems are on an ongoing trajectory of degradation, as evidenced by regional patterns of coral and fish declines (Liu et al., 2009; Kuo et al., 2012). The coastal area of Nanwan Bay is also threatened by the thermal effluent water from a nearby nuclear power plant, which has directly led to coral bleaching (Huang and Hung, 1987; Hung et al., 1989; Su et al., 1987, 1989) and other negative impacts on the marine biological community (Chou et al., 2004). In addition, coral disease outbreaks (Liao et al., 2007), sea anemone outbreaks (Hung et al., 1998), overfishing and poaching (Polunin and Roberts, 1996), and snorkeling-induced coral destruction (Meng et al., 2007a,b) have also contributed to the deterioration of KNP's coral reef ecosystems. Furthermore, physical disturbance and sedimentation by typhoons (Rogers, 1990; Hung et al., 2010; Kuo et al., 2011; Shih et al., 2013), cold water intrusion onto the shelf during spring tides (Lee et al., 1997, 1999a,b), and other natural phenomena have negatively affected the coral reefs within Nanwan Bay. The lack of seawater quality data both before and after such unpredictable marine incidents (Su et al., 1989; Hsieh et al., 2008) as well as, more generally, the absence of a long-term seawater quality dataset, thwarts efforts to determine how seawater quality changes affect the coral reef environments of Nanwan Bay. As such, there is a need for a long-term, real-time data collection system to monitor seawater quality within Nanwan Bay.

There is an increasing amount of evidence to suggest that changes in temperature and acidification associated with global climate change can adversely affect coral reefs (D'Croz and Maté, 2004; Cao et al., 2007; Hoegh-Guldberg, 1999; Hoegh-Guldberg

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et al., 2007; Veron, 2008). Electronic precision instruments for ocean monitoring and transmission technologies are constantly being improved such that the ability to collect seawater quality data in real-time over a long-term timescale is extremely feasible. These technologies can therefore facilitate our understanding of, for instance, how climate change will influence not only temperature and pCO_2, but also other seawater quality parameters, such as water quality, and how such cumulative seawater quality changes will affect the biology of these ecosystems. Furthermore, international advances made to protect marine environments rely on continuous, real-time systems to monitor abiotic factors of coral reef systems. Currently, the coral reef warning system is dominated by the U.S. National Oceanic and Atmospheric Administration (NOAA), which monitors 24 coral reef systems around the world using the Degree Heating Weeks (DHW) indicator (http://coralreefwatch.noaa.gov/satellite/current/products_vs.html).

Presently, Nanwan Bay is not monitored with a coral reef warning system. In this study, we introduce a continuous real-time monitoring system that collected seawater quality data within Nanwan Bay. Furthermore, we demonstrate the utility of the data collected with this system by investigating biological and ecological processes affected by rapid temperature changes, including coral spawning. As such, this study provides a considerable contribution and an important first step to the conservation and scientific study of the coral reef environments of Nanwan Bay and KNP.

2. Materials and methods

The continuous, real-time monitoring system (CRTMS) consists of a wireless transmission system and a solar panel that was mounted to a buoy anchored to the seafloor near the nuclear power plant (NPP) inlet (Fig. 1). The multi-parameter water quality sondes (YSI 6600) includes sensors to measure temperature, conductivity, sea level, pH, turbidity, and dissolved oxygen (DO). The specifications for precision and accuracy for all measured parameters are shown in Table 1 and were conducted following our governmental QA/QC regulations with the EPA/ROC (Taipei) methods. The procedure and frequency of periodic calibration of the equipment used in the monitoring must be specified. In this study, we calibrated the sensors every two weeks for all parameters; the frequency of all parameters measurement is ten minutes. The percentage of relative error for all the parameters reached the acceptable range after calibration.

Table 1
The specifications for precision and accuracy of all measured parameters.

Sensor	Accuracy (%)	Precision (%)
Temperature	99.9	0.8
Salinity	99.9	0.18
pH	99.9	0.43
Dissolved oxygen	100.4	4.55
Turbidity	100.3	6.12

Salinity: IAPSO STANDARD SEAWATER (Batch: P152, 34.993 psu).
pH: Merck Buffer pH4, pH 7, pH 10 and traceable to Standard Reference Material (SRM) from NIST and PTB.
Dissolved Oxygen: Air saturation.
Turbidity: HACH Formazin Turbidity Standard- 4000 NTU.

The CRTMS was deployed at a living coral reef in Nanwan Bay at 10 m depth (Fig. 2, N21°57.016′, E120°45.372′). The measured data was transmitted to a control center at Taiwan's National Museum of Marine Biology and Aquarium (NMMBA) via wireless transmission of General Packet Radio Service (GPRS). In addition to instant access, the real-time data acquired was appended to historical information within a database at the control center. Lastly, if any abnormal condition occurred, an immediate warning signal was set to display at the control center so that personnel could act accordingly and back up all monitoring data. Additional analysis of phosphate, nitrate, nitrite, and ammonia concentrations was measured every 3-months as described in Liu et al. (2012) and appended to the database.

Corals of Southern Taiwan have been shown to be stressed when the sea surface temperature (SST) is 1 °C warmer than the maximum monthly mean (MMM; Tung et al., 2007). As such, one degree above the MMM is referred to as the "bleaching threshold" temperature. Degree Heating Weeks (DHW) is an indicator to determine the magnitude of coral bleaching in a short time period (http://coralreefwatch.noaa.gov/satellite/current/products_vs.html). A value of 1 in the DHW index (0–16) indicates that the seawater temperature

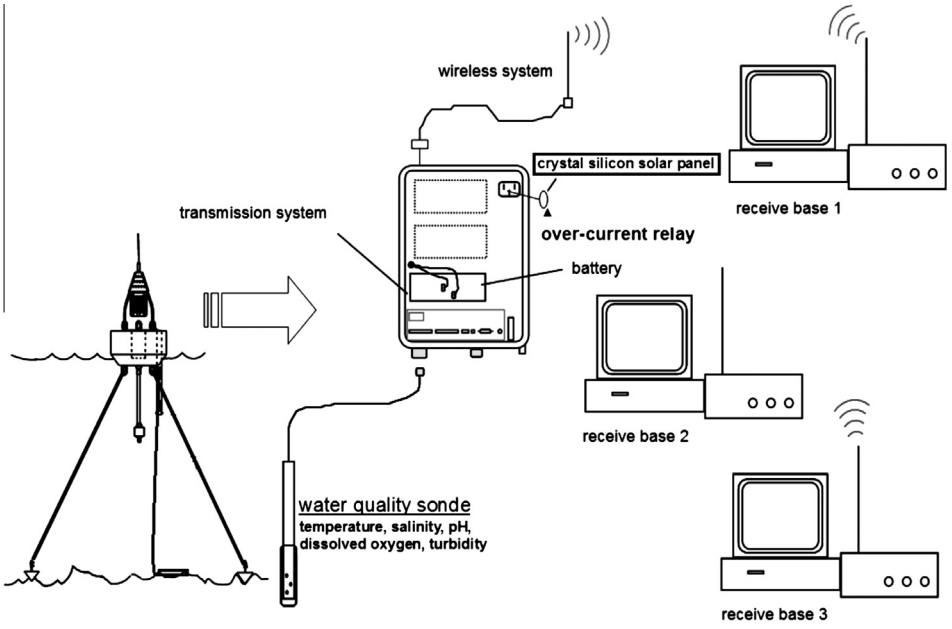

Fig. 1. A schematic of the online, real-time seawater quality monitoring system.

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