Ecological Informatics 22 (2014) 44–51

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Real-time observation, early warning and forecasting phytoplankton blooms by integrating *in situ* automated online sondes and hybrid evolutionary algorithms

Lin Ye *, Qinghua Cai *, Min Zhang, Lu Tan

State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, the Chinese Academy of Sciences, Wuhan 430072, PR China

ARTICLE INFO

Article history:
Received 4 August 2013
Received in revised form 16 April 2014
Accepted 29 April 2014
Available online 5 May 2014

Keywords:
Early warning
Eutrophication
Hybrid evolutionary algorithm
Phytoplankton blooms
Real-time observation
Three Gorges Reservoir

ABSTRACT

Phytoplankton bloom is one of the most serious threats to water resource, and remains a global challenge in environmental management. Real-time monitoring and forecasting the dynamics of phytoplankton and early warning the risks are critical steps in an effective environmental management. Automated online sondes have been widely used for *in situ* real-time monitoring of water quality due to their high reliability and low cost. However, the knowledge of using real-time data from those sondes to forecast phytoplankton blooms has been seldom addressed. Here we present an integrated system for real-time observation, early warning and forecasting of phytoplankton blooms by integrating automated online sondes and the ecological model. Specifically, based on the high-frequency data from automated online sondes in Xiangxi Bay of Three Gorges Reservoir, we successfully developed 1–4 days ahead forecasting models for chlorophyll *a* (chl *a*) concentration with hybrid evolutionary algorithms (HEAs). With the predicted concentration of chl *a*, we achieved a high precision in 1–7 days ahead early warning of good (chl *a* < 25 μg/L) and eutrophic (chl *a* 8–25 μg/L) conditions; however only achieved an acceptable precision in 1–2 days ahead early warning of hypertrophic condition (chl *a* ≥ 25 μg/L). Our study shows that the optimized HEAs achieved an acceptable performance in real-time short-term forecasting and early warning of phytoplankton blooms with the data from the automated *in situ* sondes. This system provides an efficient way in real-time monitoring and early warning of phytoplankton blooms, and may have a wide application in eutrophication monitoring and management.

1. Introduction

Phytoplankton bloom, a relatively rapid increase or accumulation of algal biomass in aquatic ecosystems, is a major threat to global water resources (Anderson et al., 2002; Carpenter et al., 1998). Algal bloom may occur in freshwater or marine environments, and it has attracted worldwide concerns because phytoplankton bloom might pose serious risks to human health, fisheries, and water resource sustainability (Allen et al., 2008; Conley et al., 2009; Sellner et al., 2003; Wu and Xu, 2011). Although the general relationships between environmental conditions and phytoplankton dynamics have been extensively studied in the past decades (Conley et al., 2009; Holmes et al., 1973; O'Brien, 1972), the dynamics and causalities of algal bloom are still not fully understood. As a result, the prediction and early warning of algal bloom dynamics remain a difficult problem worldwide (Allen et al., 2008; Lee et al., 2003).

In the past decades, a wide variety of predictive models and algorithms, including physical-process based models (Jorgensen and Nielsen, 1994; Wu and Xu, 2011), artificial neural network (Jeong et al., 2006; Recknagel et al., 2006; Ye and Cai, 2009), and evolutionary algorithms (Recknagel, 2013; Recknagel et al., 2013, 2014), have been developed to forecast the dynamics of phytoplankton. Since algal blooms are considered as a result from an excess of nutrients, particularly nitrogen (N) and phosphorus (P) (Conley et al., 2009), most of the existing models emphasize nutrient availability (*e.g.* N and P) as key input for their predictions (Cao et al., 2006; Lee et al., 2003; Wai et al., 2007; Wu and Xu, 2011).

Predictive models based on nutrient availability appear to be promising tools for effective water resource management. However, the classic chemical analysis of N or P is time consuming (*i.e.*, a few days for the field sampling, transportation, chemical analysis, and data quality control in the laboratory), resulting in time-lags for running the predictive models, limiting the efficiency for early warning of phytoplankton blooms. Future development of early warning systems should therefore be based on input variables which are easily and rapidly measured.

In recent years, the fast development of field observation instruments has allowed the creation of *in situ* real-time monitoring systems of eutrophication and algal blooms (Le Vu et al., 2011; Lee et al., 2005; Pomati et al., 2011; Richardson et al., 2010). In most of these systems, chl *a* concentration and water quality variables (*e.g.* pH, dissolve oxygen, water temperature) are measured *in situ* with automated sondes

* Corresponding authors at: Institute of Hydrobiology, the Chinese Academy of Sciences, 7# Donghu South Road, Wuhan 430072, PR China. Tel.: +86 27 68780865.
E-mail addresses: yelin@ihb.ac.cn (L. Ye), qhcai@ihb.ac.cn (Q. Cai).

http://dx.doi.org/10.1016/j.ecoinf.2014.04.001
1574-9541/

(sample frequency: seconds to hours depending on user settings). For instance, Lee et al. (2005) have deployed a real-time observation system of coastal algal blooms in sub-tropical waters around Hong Kong. In that system, chlorophyll fluorescence, pH, salinity, dissolved oxygen, water temperature, tidal level and current, photo-synthetically available radiation (PAR), global solar radiation, air temperature, wind speed and direction are measured every 1–6 h. High-frequency online monitoring systems of phytoplankton dynamics are indeed within the European Water Framework Directive (Le Vu et al., 2011). Automated sondes have been demonstrated their convenience and reliability for real-time monitoring of aquatic-ecosystem dynamics. However, the use of those monitoring data (often online) to develop short-term algal bloom forecasting and early warning, is still limited.

The overall goal of the present study is to develop a real-time system for the monitoring, forecasting, and early warning of phytoplankton blooms by integrating high-frequency automated online sondes and ecological informatics techniques. To achieve this goal, we focus on: 1) developing an automated online monitoring system for real-time observation of phytoplankton blooms; 2) developing and testing the performance of hybrid evolutionary algorithms in 1–7 days ahead forecasting of daily dynamics of phytoplankton biomass using the data furnished by the automated online monitoring system; and 3) testing the performance of hybrid evolutionary algorithms in early warning of phytoplankton blooms.

2. Methods

2.1. The integrated system for phytoplankton monitoring and forecasting

As shown in Fig. 1, the designed online monitoring, early warning and forecasting system for phytoplankton blooms is composed by three parts: i) the real-time online observation system in the field, which is designed for continuous monitoring of the concentration of chl *a* and related physical, chemical, and meteorological variables; ii) the data center in the laboratory, which retrieves and storages the real-time monitoring data from the field devices; and iii) the forecasting and early warning models for phytoplankton dynamics, in which 1–7 days ahead chl *a* forecasting model were developed to predict dynamics of phytoplankton blooms.

In the real-time online monitoring system, the data logger (Geoprecision Internet Logger/i-Log12V, Germany) controls the operation of all the physical, chemical, and meteorological sondes, logs the data obtained from these sensors, and periodically transfers the measured data from the field to the data center in the laboratory *via* the wireless network of General Packet Radio Service (GPRS). The water quality parameters, including chl *a*, conductivity, water temperature, dissolved oxygen, turbidity, oxidation reduction potential, and pH were measured by a multi-parameter sonde (YSI 6600 EDS, USA), which has an auto-clean function designed for the long-term monitoring in the field. In addition, to guarantee the accuracy in field measurements, in general, all sondes were checked and cleaned manually every 1–2 days. The meteorological variables, including wind speed, air temperature, relative humidity, air pressure, and precipitation, were measured by a small weather station (Vaisala WXT 520, Finland). Although the monitoring frequency in our system is every five minutes, the measurements at 10:00 AM were used to calibrate and validate the developed models as we focused on developing a daily time step forecasting model. Note that the online precipitation data from an adjacent national meteorological station (Xingshan station) was used in this study because the equipment in that station provides more accurate precipitation data.

2.2. Location

The real-time phytoplankton dynamics monitoring system was set up in 2008 and has been successfully working in Xiangxi Bay of Three Gorges Reservoir for over 6 years. The Xiangxi Bay is facing serious eutrophication problems because of pollutants from its watershed and related phytoplankton blooms in the bay (Xu et al., 2009a; Ye et al., 2006, 2009). The online-monitoring system is located about 19 km from the

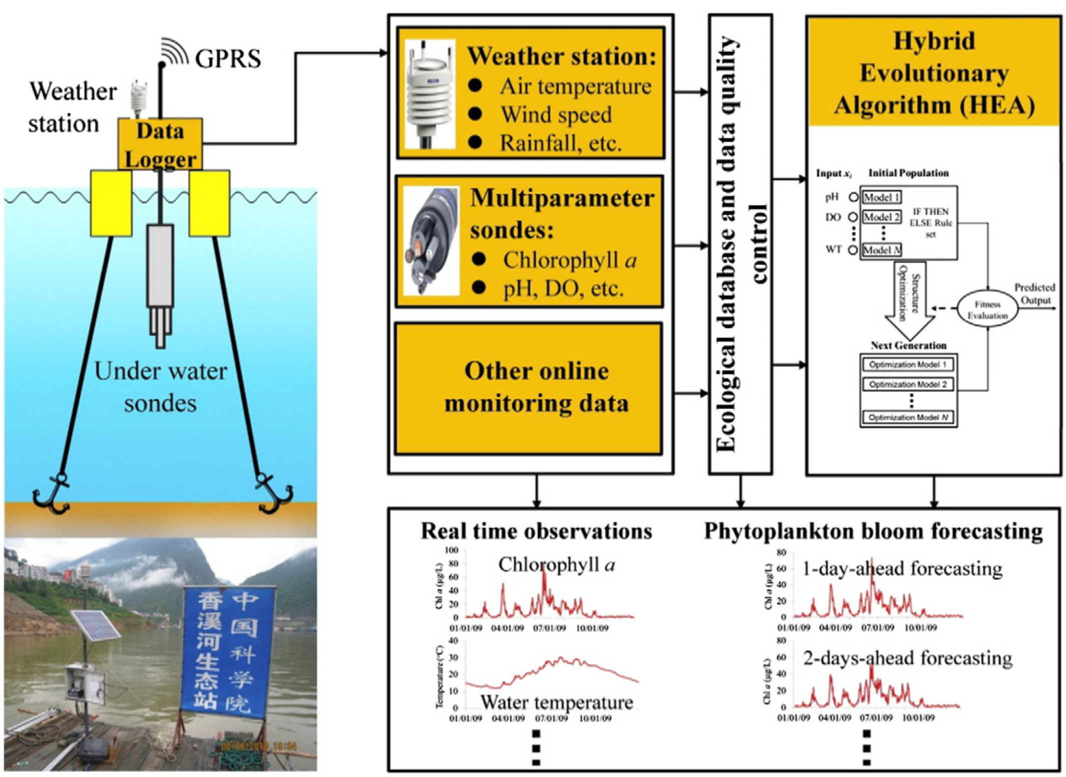

Fig. 1. Schematic diagram of real-time observation, early warning and forecasting system for phytoplankton blooms by integrating automated online sondes and hybrid evolutionary algorithm.