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Original research article

Trends in a satellite-derived vegetation index and environmental variables in a restored brackish lagoon

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HIGHLIGHTS

- We used NDVI dataset to evaluate plant productivity after lagoon restoration.
- Plant productivity was mainly regulated by mean salinity level.
- Lagoon salinity influenced by seawater exchange than freshwater input.
- NDVI and lagoon salinity was further influenced by El Niño/Southern oscillation.

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ABSTRACT

We evaluated relative influence of climatic variables on the plant productivity after lagoon restoration. Chilika Lagoon, the largest brackish lake ecosystem in East Asia, experienced severe problems such as excessive dominance of freshwater exotic plants and rapid debasement of biodiversity associated with decreased hydrologic connectivity between the lagoon and the ocean. To halt the degradation of the lagoon ecosystem, the Chilika Development Authority implemented a restoration project, creating a new channel to penetrate the barrier beach of the lagoon. Using a satellite-derived normalized difference vegetation index (NDVI) dataset, we compared the trend of vegetation changes after the lagoon restoration, from April 1998 to May 2014. The time series of NDVI data were decomposed into trend, seasonal, and random components using a local regression method. The results were visualized to understand the traits of spatial distribution in the lagoon. The NDVI trend, indicative of primary productivity, decreased rapidly during the restoration period, and gradually increased (slope coefficient: 2.1×10^{-4}, $p < 0.05$) after two years of restoration. Level of seawater exchange had more influences on plant productivity than local precipitation in the restored lagoon. Higher El Niño/Southern Oscillation increased sea level pressure, and caused intrusion of seawater into the lagoon, and the subsequently elevated salinity decreased the annual mean NDVI. Our findings suggest that lagoon restoration plans for enhancing interconnectivity with the ocean should consider oceanographic effects due to meteorological forcing, and long-term NDVI results can be used as a valuable index for adaptive management of the restoration site.

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1. Introduction

Diverse ecosystems have undergone significant degradation, with negative impacts on biological diversity and ecosystem functions (Munang et al., 2011; Staudinger et al., 2012; Turner et al., 2015). Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER, 2006). It is an intentional activity that initiates or accelerates an ecological pathway towards a reference state. Even though a variety of restoration projects have been conducted on impaired ecosystems, monitoring of the restored sites was limited or continued only for a short period (Bash and Ryan, 2002; Parkes et al., 2012). Regular monitoring during the restoration process is a preliminary requirement for adaptive management and evaluation of a restoration program. It is difficult to evaluate the restoration without considering the long-term response of the target site (Corbin et al., 2015; Daws and Koch, 2015; Thomasen and Chow-Fraser, 2012). In many restoration cases, influence of climatic cycles was usually not considered, even though they are related with fundamental issues for long-term management of restored sites (Hossack et al., 2013; Prober et al., 2015). A more nuanced understanding of the time series change during the restoration is important to ecological restoration research.

Remote sensing is being increasingly applied in diverse disciplines, based on progress in the public distribution of remotely sensed dataset (e.g., SPOT, MODIS, and Landsat). Various remote sensing techniques and instruments have been applied to monitor changes in natural ecosystems (Kerr and Ostrovsky, 2003). Satellite data products have global coverage and decadal time spans. The continuity of global monitoring can provide accurate evaluation of time-related changes, which is difficult to achieve in the field without a long-term scheme. Among the many different approaches, photosynthetic indices are effective indicators of ecosystem change, and have been used to monitor the characteristics of plant productivity in diverse ecosystems, including forests (Czerwinski et al., 2014; Soudani et al., 2012), tundras (Gamon et al., 2013), agricultural fields (Johnson, 2014), deserts (Jamali et al., 2014), lakes (Feng et al., 2012; Sima et al., 2013), lagoons (Bresciani et al., 2014), and coastal ecosystems (Rahman et al., 2011). The use of satellite-derived products would benefit the process of quantifying ecosystem changes caused by natural disturbances and artificial alterations (Goetz et al., 2006; Goodin and Henebry, 1997; Schroeder et al., 2011). Recently, Tian et al. (2015) and Zhang et al. (2012) used NDVI to evaluate relative influence of climate change and ecological restoration in dry lands. Norman et al. (2014) compared riparian vegetation response in control sites and marsh restoration sites for 27 years. Leon et al. (2012) examined effects of pre-fire restoration treatment and long-term vegetation recovery based on satellite images. Remote sensing provides unique evaluation tool for long-term monitoring of restoration sites.

Our main goal was to assess response of plant productivity to lagoon restoration in the Chilika lagoon through considering water quality and atmospheric cycles in order to provide useful data to be considered in future lagoon restoration programs. We hypothesized influence of oceanographic circulation will mostly modulate internal status (i.e. salinity, productivity) in the lagoon after mouth restoration. We discussed important restoration issues, including (1) what is the trend of recovery of plant productivity after lagoon restoration?, (2) which environmental factors, local freshwater input (precipitation) or seawater exchange, is more relevant to change of plant productivity in the restored lagoon? We tested these questions by using a remote sensing technique to estimate changes in plant productivity. We analyzed the trend in normalized difference vegetation index (NDVI) from 1998 to 2014 at Chilika Lagoon, and correlated the NDVI values with meteorological variables and water quality. We also expected that the trend in NDVI would reflect the ecological response of plant productivity in the restored lagoon, and have a distinctive relationship with changes in the lagoon environment.

2. Materials and methods

2.1. Study site

Chilika Lagoon (19° 43′N, 85° 19′E) covers an area of more than 1165 km^2, and is the largest tropical lagoon in the world (Fig. 1). The average length and breadth of the lagoon are about 64.3 km and 20 km, respectively. It bears a wide range of sub ecosystems, such as freshwater marshes, mudflats, sand dunes, and a shallow brackish lake (average depth: 1.4 m). In 1981, Chilika Lagoon was designated as the first Indian wetland of international importance under the Ramsar Convention, due to its rich biodiversity, which includes a unique assemblage of brackish species and millions of migratory waterfowl. A tropical monsoon climate prevails over the drainage basin of the lagoon. The lagoon experiences southwest and northeast monsoons in May to August and November to December, respectively. Chilika Lagoon is a tributary of the Mahanadi River. Three major tributaries of the Mahanadi that drain freshwater to the lagoon are the Daya, Nuna, and Bhargavi, located north of the lagoon. The lagoon is mostly enclosed from the Bay of Bengal, and connected to the sea by only a few channels. The Palur Canal, which is located south of the lagoon, is another point where the lagoon interacts with the sea. The lagoon's water exchange with the Bay of Bengal is mainly through the lagoon mouths, which are located in the outer channel, at its southeastern end. The old mouth was located at the end of the outer channel (Fig. 1).

Chilika Lagoon has been subjected to constant pressures from both natural and anthropogenic factors (Pattanaik, 2007). The management problems have been siltation, degradation in salinity gradient, infestation of invasive macrophytes, and aquaculture activities, resulting in loss of productivity and biodiversity. As the old lagoon mouth channel was closed because of long shore sediment transport, the weak circulation of lagoon water and poor tidal influx further complicated the conditions, leading to deterioration of the environment. As seawater exchange was limited by choking of the lagoon inlet,