Assessment of the Impacts From the World's Largest Floating Macroalgae Blooms on the Water Clarity at the West Yellow Sea Using MODIS Data (2002–2016)

Lin Li, Qianguo Xing, Xuerong Li, Dingfeng Yu, Jun Zhang, and Jingqiu Zou

***Abstract*—Water clarity (Secchi disk depth, SDD) is a very important factor for marine ecological environment. The world's largest "green tide" caused by the macroalgal blooms (MABs) of green macroalgae has occurred every summer in the Yellow Sea since 2008. In this study, we first present the effects of MABs on the water clarity in the west Yellow Sea. A regional empirical retrieval algorithm of SDD on the basis of moderate resolution imaging spectroradiometer (MODIS) remote sensing reflectance is evaluated with the field data and satellite reflectance data: the spectral simulation with the end-member reflectance of sea water and macroalgae, and the MODIS Level-2 standard products of the remote sensing reflectance. The results show that the mixture of sea water and macroalgae will lead to decreased water clarity when the SDD is larger than 1.2 m and increased chlorophyll-a, i.e., false values in the standard products for pure sea water which therefore should be used with caution for the regions with large scale of floating macroalgae blooms. The long-term SDD in June and July (2002–2016) over the Yellow Sea is investigated and analyzed with the presence of "green tide." The significant decrease in the SDD by 2.6 m and with 12 544 km^2 of sea surface in total in July while no pronouncing changes in June suggests that the water clarity in the west Yellow Sea has been strongly affected from the period of 2002–2007 (the pre-MAB phase) to the period of 2008–2016 (the MAB phase).**

***Index Terms*—Macroalgal blooms, moderate resolution imaging spectroradiometer (MODIS), secci disk depth, the Yellow Sea, water clarity.**

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L. Li is with the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003, China, and also with the School of Opto-Electronic Information Science and Technology, Yantai University, Yantai 264005, China (e-mail: jessyll@163.com).

Q. Xing, X. Li, and D. Yu are with the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003, China (e-mail: qgxing@yic.ac.cn; xrli@yic.ac.cn; dfyu@yic.ac.cn).

J. Zhang is with the School of Opto-Electronic Information Science and Technology, Yantai University, Yantai 264005, China (e-mail: jzhang@ytu.edu.cn).

J. Zou is with the Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China (e-mail: zoujinqiu@caas.cn).

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I. Introduction

WATER clarity (or water transparency) is an important optical factor for marine environment [1], which is usually measured with the Secchi disk depth (SDD, m^{-1}). In practice, the SDD is measured by the depth when a Secchi disk is no longer viewable by an observer's eyes when it is lowered into the water [2], [3]. For ocean or lake waters, the SDD is mainly regulated by the content of phytoplankton, mineral particles, and yellow substances, and thus it is widely used in the assessments of water quality and eutrophication. With the aid of remote sensing techniques, the SDD can be estimated with high accuracy over large areas. Different models have been developed for the estimation of SDD. Doron *et al.* adapted and developed empirical and semianalytical algorithms to monitor the SDD using medium resolution imaging spectrometer, moderate resolution imaging spectroradiometer (MODIS) and sea-viewing wide field-of-view sensor data [4]. Al Kaabi *et al.* proposed a regional algorithm to retrieve the water clarity in the Arabian Gulf using MODIS aqua data [5]. Lee *et al*. obtained high-spatial-resolution map of water clarity using Landsat-8 images [6].

Researchers have found that there is a negative exponential relationship between chlorophyll and water transparency [7], [8]. Carlson observed that the SDD was highly correlated with chlorophyll-a (Chl-a) with a correlation coefficient of 0.93 [7]. Megard and Berman examined the relationship between the chlorophyll concentration and the water transparency in the southeastern Mediterranean Sea [8]. Morel *et al.* proposed to use the chlorophyll concentration as an intermediate tool to estimate the SDD for global case-I waters [9].

In recent years, the occurrences of marine macroalgae blooms like the "green tide" caused by green macroalgae and the "golden tides" caused by Sargassum, have been reported to increase all over the world [10]–[16]. The large scale of floating macroalgae covering the sea surface may lead to important impacts on the marine system [17]. Xing *et al.* reported that the green tide caused a significant decrease in the biomass of phytoplankton in summer, and changed the phenology of phytoplankton in the southwest Yellow Sea [18]. The optical environment, for example, the water clarity indexed by the SDD, may also be changed due to the occurrence of large-scale macroalgae blooms.