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Characterization of the development stages and roles of nutrients and other environmental factors in green tides in the Southern Yellow Sea, China

1.项目负责人

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ABSTRACT

Large-scale floating green tides in the Southern Yellow Sea (SYS) caused by the macroalgal species *Ulva prolifera* have been recurring for 13 years and have become one of the greatest marine ecological disasters in the world. In this study, we attempt to explore the development pattern of green tides and find its key environmental influencing factors. The satellite remote sensing data of the development process of green tides fit the logistic growth curve ($R^2 = 0.93$, $P < 0.01$) well, showing three distinct growth phases (lag, exponential growth, and short plateau phases). Correspondingly, the green tide-drifting area from the coast of Jiangsu to the nearshore waters of the Shandong Peninsula was divided into three sections: the lag phase zone (A), the exponential growth phase zone (B), and the plateau phase zone (C). Zone A in the south of Jiangsu coastal waters had abundant inorganic nutrients that were indispensable to the green tide initiation. Zone B was mainly located out of Haizhou Bay, south of 34.5° N and north of 35.5° N, where approximately 80% of the green tide biomass was generated. The rich bioavailable nutrient sources, suitable temperature, and irradiance in this area were the main promotion factors for the rapid growth and scale expansion of green tides. Wet precipitation in zone B in May and June also played an important role in the final scale of green tides. Zone C had poor nutrients, increasing temperature, and irradiance (high transparency), which limited the continued expansion of green tides, and organic nutrients might be an important support to green tides development in this region. The study based on the growth phases of green tides could help us further understand the eutrophication mechanism in the green tide outbreaks in SYS.

1. Introduction

Green tides caused by macroalgae *Ulva, Enteromorpha, Chaetomorpha, Cladophora*, and *Ulvaria* species had become a worldwide environmental phenomenon in some eutrophic coastal and gulf areas (Bermejo et al., 2019; Charlier et al., 2008; Fletcher, 1996; Hiraoka et al., 2010; Nelson et al., 2008; Victor and Adriana, 2013; Yabe et al., 2009; Ye et al., 2011; Zhao et al., 2018a). The large amount of macroalgal biomass could rapidly absorb nutrients and release allelochemicals that limit the growth of other plankton (Tang and Gobler, 2011), change the ecosystem structure, and decrease biodiversity (Gladyshev and Gubelit, 2019; Lotze and Worm, 2000; Lyons et al., 2014). In addition, the floating green tide patches would affect the sunlight reaching the deep layers, which would result in primary production decline (Lyons et al., 2014; Sun et al., 2018). The seagrass beds would degenerate and reduce the yields of marine products (Miao et al., 2018). When algae accumulate, sink, and die on shore or sea, the decomposition of macroalgae would consume the dissolved oxygen, cause a local hypoxia or oxygen-depleted zones (Norkko and Bonsdorff, 1996), and release a large amount of sulfur compounds; such release would not only damage the production of coastal mariculture (Le Luherne et al., 2016; Paumier et al., 2018) but also prevent people from using the waterfront area covered by macroalgae, which in turn would influence the development of tourism economy in coastal cities (Nelson et al., 2008).

In the Southern Yellow Sea (SYS) in China, large-scale free-floating green tides formed by the macroalgae species *Ulva prolifera* had been recurring for 13 years since 2007 (Keesing et al., 2011; Liu et al., 2009; Zhao et al., 2018a). Previous cruise field surveys showed that the small scatter patches of green tide algae (including several *U.* species) (Duan et al., 2012; Fan et al., 2015; Song et al., 2015; Wang et al., 2018) were first observed along the *Porphyra* agriculture area of

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factors contributed to the different growth phases and development characteristics. The results could be helpful in further understanding the outbreak mechanisms of green tides in the SYS.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hal.2020.101893.

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