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Economic assessment and environmental management of green tides in the Chinese Yellow Sea

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ABSTRACT

Green tides are part of the larger class of harmful algal blooms (HAB), and have developed worldwide at a high rate during the last three decades, favoured by the eutrophication of coastal waters due to human activities. The massive accumulation of seaweeds on the shore resulting from green tides generates a variety of damages to market and non-market activities, and is a potential threat to human health. This work focuses on the green tide phenomenon in the Chinese Yellow Sea, and provides an economic assessment in a cost-benefit perspective. It first investigates the bioeconomic mechanisms of these episodes, their economic consequences, public management policies, and stakeholders' perceptions. Then, it tries to quantify the social cost of green tides, including management costs and residual costs to market and non-market activities. On this basis, alternative management scenarios are compared.

1. Introduction

Harmful algal blooms (HABs) are blooms of micro or macro-algae, which are not necessarily toxic but, due to their massive character, generate various damages to ecosystems, human activities, and/or human health (Anderson et al., 2012; Zingone and Oksfeldt Enevoldsen, 2000). These blooms have increased worldwide during the last three decades (Glibert and Pitcher, eds, 2001; Hallegraeff, 1993; Kudela et al., 2015; Smetacek and Zingone, 2013; Zhang et al., 2012), as a mixed result of natural and anthropic factors (Sellner et al., 2003). Industrial, urban and agricultural pollutions are frequently mentioned in the literature as favouring HABs (Anderson et al., 2008; Chevassus-au-Louis et al., 2012; Dodds and Smith, 2016; Heisler et al., 2008; Menesguen and Piriou, 1995).

HABs occur in marine waters as well as in continental waters (Paerl et al., 2001; Smith, 2016). Marine HABs are frequently referred to as “coloured” tides, due to the colour algae give to the water (Gower and King, 2011; Menesguen and Piriou, 1995; Smetacek and Zingone, 2013). Green tides are a specific category of HABs, caused by massive proliferations of green macro-algae, mainly belonging to the family of ulvaceae (Charlier et al., 2007; Hiraoka et al., 2004; Sfriso and Marcomini, 1996; Zhang et al., 2009). These tides are seasonal, and have occurred increasingly in various coastal areas of Europe and Asia during the last decades. Their biological drivers have been extensively investigated, and it appears that massive blooms of green algae are made possible by the increased eutrophication of coastal waters (Anderson et al., 2008). The factor that limits the proliferation of green algae is usually nitrogen, which suggests that intensive farming activities in coastal areas play a critical role in the burst of green tides (Chevassus-au-Louis et al., 2012).

Green algae are not toxic when they are alive. They are used as food for human beings, and are increasingly regarded as a natural resource that might be turned into a variety of valuable products through industrial processing (Guillas, 2013; Yang, 2016). However, massive landings of green algae in coastal areas are harmful for a variety of human activities, and may be hazardous to human health, due to the emission of hydrogen sulphide during their decay (Boudet et al., 2011; Pucheux et al., 2011; Tauzède et al., 2009). Moreover, in some cases green tides are suspected to favour blooms of toxic microalgae known as “red tides” (Wang et al., 2012).

Damages caused by HABs may belong to four major categories: human health, fishing and aquaculture, tourism and recreational activities, marine ecosystems (Anderson et al., 2012; Zingone and Oksfeldt Enevoldsen, 2000). The economic assessment of these damages may be a useful tool for public policies. Several methodologies have been proposed and implemented for this assessment, with a

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distinction between market and non-market values (Bergha et al., 2002; Hoagland et al., 2002, 2014; Larkin and Adams, 2013; Nierenberg et al., 2011). However, in the case of green tides, little has been done up to now in this field. As regards green tides occurring in Brittany (France), some figures are available concerning algae harvesting and processing costs (Charlier et al., 2007; Guyomarc'h and Le Foll, 2011), and a recent attempt was made to give a non-monetary estimation of the impact of green tides on tourist attendance (CGDD, 2017).

The subject of this paper is the economic assessment and management of green tides, in a cost-benefit perspective. The analysis relies on a case study, concerning green tides that have developed each spring in the Chinese Yellow Sea during the last decade (Liu et al., 2013). In order to assess the social cost of these episodes, we first investigate their bio-economic mechanisms, their economic consequences, the public management policies that have been adopted up to now, and stakeholders' perceptions (section 2). This investigation is based on the following sources: i) bibliographical survey of scientific literature; ii) public statistical data; iii) interviews of scientists, representatives of local government, administrative bodies in charge of the management of green tides, and economic stakeholders; iv) field survey of local population and tourists. Based on this investigation, the following section is dedicated to quantifying the social cost of green tides, which provides a basis for comparing alternative management scenarios. Main results are summed up and discussed in section 4.

2. The case of green tides in the Yellow Sea

Our case study is located in the Chinese waters of the Yellow Sea and the coastal zones of Jiangsu and Shandong (Fig. 1), two densely populated and highly developed provinces of Eastern China (2013 population density: 773 inhabitants per km^2 in Jiangsu; 617 inhabitants per km^2 in Shandong; 2013 GDP per capita, as a percentage of average national GDP per capita: 179% in Jiangsu; 135% in Shandong) (Statistical Communiqué on Shandong's and Jiangsu's Economic and Social Development on 2013). After summing up scientific evidence concerning the origin and drivers of green tide episodes in the Yellow Sea, we describe the impacts of these episodes on ecosystem services and human activities, and the responses that, up to now, have been provided by public authorities. Finally, we present the main results of two field surveys concerning perceptions of the phenomenon that were undertaken within the framework of our study.

Fig. 1. Case study area.

Table 1
Yellow Sea green tides: maximum covered and repartition areas, 2008–2014.
Source: SOA, China maritime disasters bulletin, 2008 to 2014

Year	Maximum covered area (km^2)	Maximum repartition area (km^2)
2008	650	25,000
2009	2100	58,000
2010	530	29,800
2011	560	26,400
2012	267	19,610
2013	790	29,733
2014	540	50,000

2.1. Origin and drivers

In the beginning of the summer of 2008, the sudden massive arrival of green algae on the shore of the large harbour city of Qingdao (Southern coast of Shandong), that was about to host the sailing competitions of the Olympic games, stirred the world attention on green tides (Leliaert et al., 2009). It is estimated that about 1 million tons (wet weight) washed up on the coast, and that two additional million tons sunk (Sun et al., 2008). Since 2008, green tides have occurred in this area each year, with a varying intensity (Liu et al., 2013) (Table 1).

Scientists have investigated the question of the origin and drivers of these tides. The state of the art may be summed up as follows. I) The dominant species in the Yellow Sea green tides episodes is Ulva prolifera, an opportunistic and fast-growing seaweed (Liu et al., 2010b; Zhang et al., 2013; Zhou et al., 2015). This species is not indigenous in the coastal waters of Shandong, where the winter temperature is too low (Liu et al., 2009b). Reserves of propagules are found in the warmer coastal waters of Jiangsu (Pang et al., 2010). However the high turbidity of these waters is a challenge to the growth of young ulvae, because it hinders photosynthesis. ii) This barrier may be bypassed, thanks to the presence in the area of rafts and nets that are used by farmers growing a red alga called nori (Porphyra yezoensis): these facilities provide a substratum where young ulvae may settle and grow (Liu et al., 2009a). At a certain stage of their life cycle, the tubular structure of Ulva prolifera makes it possible for them to float at the surface of the sea, thus capturing sunlight easily, and growing fast. iii) Nori farmers regard the presence of ulvae that are intermingled in their facilities as a plague, because it lowers the value of their product. As a result, when harvesting nori, they have to spend time sorting out ulvae, which they usually discard at sea, thus favouring their dissemination (Liu et al., 2010a). iv) Proliferation of ulvae is fuelled by the increased eutrophication of Jiangsu coastal waters (Hu et al., 2010), due to large inputs of dissolved inorganic and organic nitrogen that are drained by coastal rivers, and possibly to the plume of the Yangtze river delta, south of Jiangsu. These inputs are provided by various sources, especially farming activities and poor wastewater treatment. Among these sources, the rapid development of crab farming in the Jiangsu province, from 2005, is suspected to have played a triggering role in the breakout of green tides in 2007. This development is based on the so-called FCM technology: fermented chicken manure is used as feed for rotifers, which are themselves used as feed for crabs (Liu et al., 2013). v) Under the action of winds and currents, layers of green algae that develop in Jiangsu waters drift northward and reach the coast of Shandong. During this process, their biomass rapidly grows (Fig. 2).

To sum up, a combination of two activities seems to play a major role in the Yellow Sea green tides: crab farming that increases the eutrophication of Jiangsu waters, and nori farming that provides facilities for the settling and development of young ulvae. The simultaneous rapid growth of these two activities, in the years preceding the burst of green tides in the Yellow Sea, is regarded as a clue concerning their triggering role in the development of green tides.