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Review

Climate change and anthropogenic impacts on marine ecosystems and countermeasures in China

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Abstract

The ecosystems of China seas and coasts are undergoing rapid changes under the strong influences of both global climate change and anthropogenic activities. To understand the scope of these changes and the mechanisms behind them is of paramount importance for the sustainable development of China, and for the establishment of national policies on environment protection and climate change mitigation. Here we provide a brief review of the impacts of global climate change and human activities on the oceans in general, and on the ecosystems of China seas and coasts in particular. More importantly, we discuss the challenges we are facing and propose several research foci for China seas/coasts ecosystem studies, including long-term time series observations on multiple scales, facilities for simulation study, blue carbon, coastal ecological security, prediction of ecosystem evolution and ecosystem-based management. We also establish a link to the Future Earth program from the perspectives of two newly formed national alliances, the China Future Ocean Alliance and the Pan-China Ocean Carbon Alliance.

Keywords: Global climate change; Anthropogenic activities; Blue carbon; Coastal ecological security; Ecosystem evolution; Ecosystem-based management

1. Introduction

Since the industrial revolution, the atmospheric CO_2 levels have increased from approximately 280×10^{-6} to more than380×10^{-6} (IPCC, 2013), which is the highest in the history of the Earth for the past 800,000 years (Lüthi et al., 2008). This increase rate is believed to be faster than that happened over millions of years (Doney and Schimel, 2007). With the warming effects of CO_2, an increase of air temperature of 2.6–4.8 °C by the end of the 21st century is projected under the condition of Representative Concentration Pathways 8.5 (RCP 8.5) (IPCC, 2013). The oceans, covering more than 70% of the Earth's surface, include coastal, continental margin, open ocean, and sea-ice covered systems. The oceans play an important role in regulating climate by storing and redistributing materials, energy and heat. For example, the oceans act as the major sink for CO_2 (Le Quéré et al., 2014). Since the beginning of the 19th century, the oceans are estimated to have taken up about 50% of fossil fuel emissions and about 30% of

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anthropogenic emissions, thus significantly reducing the accumulation of atmospheric CO_2. Meanwhile, the oceans are experiencing significant variations on different space and time scales as a result of climate change, which in turn affect the human communities that rely on oceanic services and resources.

The physical and chemical features of the oceans have changed with the increased transferring of CO_2 and heat from the atmosphere (IPCC, 2013). Since the majority of the atmospheric heating induced by the increased CO_2 and other greenhouse gases was absorbed by the oceans, significant warming of the upper ocean has been reported in long-term monitoring studies. Heating of the upper ocean has led to a strong thermal stratification, and contributes to the observed global sea level rise (SLR) (IPCC, 2013). Higher sea temperatures have the potential to produce more intense storms, and the surface wind changes have changed the wave height and ocean upwelling. Increasing concentrations of atmospheric CO_2 has also influenced the chemistry of ocean waters, leading to a growing inventory of inorganic carbon. Ocean pH has declined by approximately 0.1 pH units as a result of ocean acidification (IPCC, 2013). Seawaters of low O_2 concentrations are expanding due to a number of local (i.e. eutrophication) or global drivers (i.e. increasing temperature, reduced water column mixing and ventilation).

Similarly, anthropogenic activities can produce a number of stressors (e.g. pollution, habitat fragmentation or destruction, introduction of invasive species, unsustainable fishing, hydroclimatic changes) from both land and sea that have varying impacts on different components of the marine ecosystems (Boldt et al., 2014; Rombouts et al., 2013; UNEP, 2010). There is a high risk of biological extinction and loss of vital habitats. One recent estimate found that at least 40% of the global oceans are heavily affected by human activities (IOC/UNESCO et al., 2011). Many of these effects can act additively, synergistically, or antagonistically (Korpinen et al., 2012; Rombouts et al., 2013). These changes are impairing the ocean's capacity to provide food, protect livelihoods, maintain clean water, and recover from environmental stresses like severe storms. The resilience of marine ecosystems to anthropogenic pressures is weaker than previously thought. These trends are exacerbated by the growing human populations in coastal areas and increasing need for marine resources (Claudet and Fraschetti, 2010; Rombouts et al., 2013).

China has a territorial sea area of about 380,000 km^2, and a jurisdictional sea area of 3,000,000 km^2 (Yang, 2006). The total length of its coastline is 32,000 km, with 18,000 km along mainland. China has about 7 million hm^2 of various coastal wetlands, and about 6900 islands (TLSC, 2010). Typical marine ecosystems, such as estuary, bay, lagoon, island, mangrove, coral reef, sea grass bed, etc., all exist in the China seas and coastal areas. The abundant marine natural resources and huge ecosystem service in China are important foundation and safeguard for national economic and social development. Since the 11th Five-Year Plan, China's marine economy growth rate has been higher than the national economic growth rate over the same period. The total marine production has been more than 5 trillion since 2012, which has become a new engine to drive the economic development (SOAC, 2012). However, in recent decades, China's marine and coastal ecosystems are facing a series of challenges due to the high intensity of human activity and climate change. Our artificial shoreline accounts for up to 80% of natural shoreline. The development and production activities (reclamation, oil and gas, aquaculture, shipping, etc.), as well as a sharp increase in the discharge of terrigenous nitrogen and phosphorus, organic matter, and various types of pollutants, resulted in offshore ecological disasters (eutrophication, red tide, existence and enlargement of anoxic zone) and huge economic loss. This would seriously endanger the marine ecosystem and the sustainable development of society (TRGEEP, 2010).

2. Impacts of global climate change on China seas/coasts

There are evidences that sea surface temperatures in the China seas increased in the last several decades. Since the 1980s, the Bohai Sea, Yellow Sea, and East China Sea have witnessed significant increase in sea surface temperatures (Cai et al., 2011; Lin et al., 2005, 2001). The strongest warming was observed in the East China Sea in winter (1.96 °C) from 1955 to 2005 and in the Yellow Sea in summer (1.10 °C) from 1971 to 2006 (Cai et al., 2011). The upper layer of the South China Sea warmed steadily from 1945 to 1999 (Li et al., 2002; Liu et al., 2007) and the annual mean sea surface temperatures in the central South China Sea has increased by 0.92 °C from 1950 to 2006 (Cai et al., 2008). Such a change has led to spatially non-homogeneous sea level variations (Li et al., 2002; Cheng and Qi, 2007). The projected SLR rate near China is 3.1−11.5 mm per year by 2050, higher than the global SLR rate (3.2−8.0 mm per year) (Cai et al., 2008; Yang and Sill, 1999). This implies that a total area of $(14.3-21.2) \times 10^4$ per year hm^2 might be flooded over the main coastal plain of China, which account for 2.47%−3.66% of the total coastal wetlands (Sun et al., 2015). The concentration of dissolved oxygen decreased obviously in the Yellow Sea and East China Sea (Lin et al., 2005), and the size of hypoxia areas expended in the coastal areas of the Yellow Sea/East China Sea (Tang, 2009). Severe ocean acidification has been found in the coastal water of the Bohai Sea and the Yellow Sea, and the aragonite saturation state was detected to be lower than 2 in the bottom water of most coastal zones. In particular, the autumn aragonite saturation state of the bottom water in the central Yellow Sea was down to 1, which reached the critical value for shell and skeleton dissolution (Zhai et al., 2014; He et al., 2014).

Obvious changes in biological abundance and distributions in China marine ecosystems were observed. There has been an increasing proportion of warm water species relative to temperate species from plankton to fish in the past decades in the Yangtze estuary of the East China Sea and in the south Taiwan Strait (Li et al., 2009; Lin et al., 2011; Ma et al., 2009; Zhang et al., 2005). Changes of dominant fishery species driven by multi-decadal climate variability have been reported