Environmental Pollution 241 (2018) 74–84

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Analysis of forty years long changes in coastal land use and land cover of the Yellow Sea: The gains or losses in ecosystem services

Jongseo Yim [a,1], Bong-Oh Kwon [b,1], Jungho Nam [c], Jin Hwan Hwang [d], Kyungsik Choi [b], Jong Seong Khim [b,*]

[a] Department of Geography, Seoul National University, Seoul, Republic of Korea
[b] School of Earth and Environmental Sciences & Research Institute of Oceanography, Seoul National University, Seoul, Republic of Korea
[c] Marine Policy Research Division, Korea Maritime Institute, Busan, Republic of Korea
[d] Institute of Construction and Environmental Engineering, Seoul National University, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 29 March 2018
Received in revised form
4 May 2018
Accepted 17 May 2018

Keywords:
Intertidal flat
Land-reclamation
Land cover change
Blue carbon
East Asia

ABSTRACT

The drastic land cover change and its impacts in the Yellow Sea have long been significant issues in terms of coastal vulnerabilities, but holistic data analysis is limited. The present study first reports 40 years long geographical changes of the Yellow Sea coasts including all three neighboring countries of China, North Korea, and South Korea. We delineated tidal flats by analysis of Landsat series satellite imageries (662 scenes) between 1981 and 2016. A total area of the Yellow Sea tidal flats has been considerably reducing for the past 36 years, from ~10,500 km^2 (1980s) to ~6700 km^2 (2010s), say ~1% annual loss. A majority loss of tidal flats was mainly due to the grand reclamations that conducted in almost entire coast of the Yellow Sea, particularly concentrated in the 1990s-2000s. Coastal reclaimed area during the past four decades reached ~9700 km^2, including ongoing and planned projects, which corresponds to over half the area of precedent natural tidal flats of the Yellow Sea. The potential carbon stocks in the eight representative regions with large scale reclamation indicated significant loss in carbon sink capacity in the South Korea's coast (~99%), while evidenced a lesser loss from the China's coast (~31%). It was noteworthy that the progradation of tidal flats after the reclamation in China's coast significantly reduced the loss of carbon sequestration. According to the ecosystem services valuation for the Yellow Sea, a total loss was estimated as ~8 billion USD yr^{-1} with relatively high proportional loss (up to 25%) of climate regulating services (viz., carbon sequestration). Overall, huge losses in ecosystem services being provided by the Yellow Sea natural tidal flats need immediate action to prevent or at least alleviate accelerating ecological deteriorations. Finally, future conservative policy direction on coastal wetlands management has been proposed towards enhancement of marine ecosystem services.

1. Introduction

Tidal flats play essential roles in maintaining various ecosystem services being recognized as one of the most important coastal habitats (Barter, 2002; Costanza et al., 1997; Hassan et al., 2005). Among the regions with globally recognized tidal flats, such as the Yellow Sea (~10,486 km^2), the Wadden Sea (~4000 km^2), and the Persian Gulf (~3000 km^2) (Deppe, 2000), however, the Yellow Sea might have experienced the worst ecosystem damages (MacKinnon et al., 2012). This is because of an increased societal demands for land-earning strategy in China and Korea during the past several decades, resulting in massive land reclamation of natural tidal flats in the Yellow Sea (Barter, 2002; Koh and de Jonge, 2014; Murray et al., 2014; Wang et al., 2014; Yang et al., 2011).

Land cover changes by the reclamation of natural tidal flats might brought both direct and indirect impact(s) on the coastal ecosystem services (de Jonge et al., 1993; Koh and Khim, 2014; Zhao et al., 2014). For instance, tidal flats widely developed on the frontline of the coasts of the Yellow Sea protect the hinterlands from the landward waves and tides, thus storm surge damages would increase without buffered tidal flats (Gedan et al., 2011). Coastal vegetation in the upper intertidal flat also play an important role in mitigating the climate changes by absorbing carbon up to 50

* Corresponding author.
E-mail address: jskocean@snu.ac.kr (J.S. Khim).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.envpol.2018.05.058
0269-7491/

times greater than terrestrial ecosystem (Chmura et al., 2003; McLeod et al., 2011). Thus, preservation of coastal wetlands is of great importance not only for maintaining coastal vulnerabilities but also increasing ecosystem services values (ESVs). While numerous ESVs have been considered and estimated for coastal wetlands (Camacho-Valdez et al., 2013; Cui et al., 2016; Shang et al., 2018; Sun et al., 2017; Xu et al., 2016; Ye et al., 2016; Yu and Zhang, 2011; Zhao et al., 2014), the value change by tidal flats reclamation with respect to coastal carbon sequestration has not been much emphasized.

In fact, the environmental and/or ecological impacts caused by the coastal reclamations have been consistently documented in China (An et al., 2007; Cui et al., 2016; Murray et al., 2012, 2014; Yang et al., 2011; Yu and Zhang, 2011) and Korea (Lee et al., 2014; Park et al., 2014; Ryu et al., 2014). However, the previous works mostly focused on specific region(s) and/or narrow time periods, accordingly a holistic analysis could not be given so far. While, the use of meta-data derived from individual studies would be benefit to address long-term analysis, but fundamental bias due to accuracy flaw would be another issue (An et al., 2007; Murray et al., 2012, 2014; Yang et al., 2011). Of note, the information of land cover change or historical coastal reclamations lacks in North Korea, particularly in recent 10 years. Finally, there has not been much work reporting the status and long-term changes of coastal ecosystem services in Korea (Ryu et al., 2014), of which aspect should be considered as part of the entire Yellow Sea ecosystem.

In the present study, we newly delineated the coastal wetlands, namely tidal flats, in the Yellow Sea, encompassing entire coasts of China, North Korea, and South Korea, in four decadal time periods; since the 1981 to present. The present work enabled us to describe spatio-temporal comparison cross all the coastal areas of the Yellow Sea in a consistent manner, which surely improved the its comparability between countries and/or regions. Areal loss of tidal flats due to land-reclamation and/or gain from regeneration of tidal flats could be identified in minimal dimension of 30 m × 30 m, thus net areal loss or gain in specific regions of interests was discussed. In addition, the comparative analysis of carbon stock changes in major reclaimed regions in China and Korea was provided to link long-term environmental impacts to historical reclamations in the study area.

2. Material and methods

2.1. Overall scoping and framework of the study

In the present study, we targeted the coastal areas of the Yellow Sea (Fig. 1) by adopting the geographical scope of the world's oceans, viz., the Large Marine Ecosystem (LME) (Sherman, 1994). Among the current 66 LMEs in the world, the Yellow Sea LME is regarded as one of the most significantly affected areas by human development, particularly threatened by extensive coastal reclamations (Koh and Khim, 2014). The coastal areas of the Yellow Sea encompass three countries of China, North Korea, and South Korea clockwise (Fig. 1).

To reflect the long-term historical changes in land use activities along the entire coastal areas of the Yellow Sea, time-series data of tidal flat delineation for the past 36 years was generated in this study. As part of the QA/QCs, the accuracy of tidal flat delineation results from the satellite image analysis has been verified and the proper interpretation and/or limitation were discussed (Figs. 2–3). Accordingly, areal loss or gain of the natural tidal flats along the Yellow Sea could be successfully identified and presented as decadal basis (Fig. 4). Of note, the tidal flats include the bare intertidal flats and salt marshes that situated within the intertidal zone of the study area. Net areal loss of the Yellow Sea tidal flats and/or ecological impacts due to the large-size coastal reclamations in the neighboring countries of China, North Korea, and South Korea were timely described (Table 1; Fig. 5).

2.2. Tidal flat delineation and updating reclaimed coastal areas

The Yellow Sea tidal flats were delineated by use of the remote sensing technique based on the Landsat satellite imageries, warranting advantages of spatial resolution, coverage, and availability (Hansen and Loveland, 2012). The study area consisted of 21 zones (#1-#21 in counterclockwise) of the Landsat satellite imagery (WRS-2; World Reference System 2) as shown in Fig. 1. The delineated tidal flats in each zone were merged by each country and presented as national basis.

The detailed procedures are as follows. First, we collected as many as available imageries of all zones, which have been captured for the low-tide landscapes from 1981 to 2016 from Landsat 4, 5, 7 and 8, resulting in a total of 662 scenes. Next, all the collected Landsat imageries were visually (say manually) reviewed to select representative imagery for each zone, showing the most extended area of tidal flat with least covered by clouds, ices, or fogs, within a decadal period (Fig. S1). Finally, from a total of 84 selected imageries (21 zones × 4 multi-decadal periods), tidal flats were identified and delineated by the Fuzzy K-mean unsupervised classification technique. Specifically, we subtracted coastal area before classification process and used visible, near-infrared, and mid-infrared spectral bands of the Landsat imagery in the classification process (Fig. S2; Burrough et al., 2000).

Finally, specific effort was given to collect and update the missing information of coastal reclamations within target areas and/or given time frame (viz., 4 decadal periods) for each country. In particular, we newly updated the aerial dimension of reclaimed coasts in North Korea in the 2010s (Table 1).

2.3. Verification of tidal flat delineation result

There has been debated on uncertainty in terms of accuracy in remote sensing technique, due to some possible errors in the process of acquisition followed by data analysis. Thus, the accuracy of tidal flat delineation results based on satellite imageries has been evaluated as part of the study. In this study, the delineation result of tidal flats was quantitatively compared with the most recently available data from the Ministry of Oceans and Fisheries (MOF), South Korea (Fig. 2), which was constructed from the aerial photographs and the aviation LiDAR (MOF, 2013).

Specifically, we constructed the confusion matrix between two data with randomly sampled 1000 points in coastal area of South Korea. In addition, for in-depth comparison, we constructed separate confusion matrices for points within 5, 10, 15, and 30 km, depending on the distance from the mainland of South Korea. In confusion matrix, the true positive (TP) or the true negative (TN) represents the point classified as same land cover classification between MOF data and ours (Table S1). Whilst, the false positive (FP) or the true negative (TN) indicates the point classified to be “discrepancy”, namely false-classifications or errors. The accuracy was calculated as below equation.

$$Accuracy = \frac{TP + TN}{Total\ number} \qquad \text{Eq (1)}$$

2.4. Analysis and calculation of coastal carbon stock

As for one aspect of ecological impacts caused by the reduction