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Valuation of the loss of plant-related ecosystem services caused by water stress in the wetland of China's Yellow River Delta

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ABSTRACT

China's Yellow River Delta is ecologically important because of its role as an eco-tone between terrestrial and aquatic ecosystems. However, water stress caused by drought or flooding creates ecological risks for this important ecosystem. In this study, we assessed community biodiversity, plant biomass, and the plant total nitrogen, total phosphorus, and potassium contents to quantify the potential loss of ecosystem services value arising from water stress. The annual ecosystem services and function value of the wetlands totaled 3.68×10^8 Yuan, of which biomass production and local climate regulation accounted for 39.4% and 49.5% of the total, respectively. The area with the highest value (>2 Yuan m^{-2}) lies along both banks of the downstream reaches of the river, whereas areas with the lowest values (<1.5 Yuan m^{-2}) were located on the northern bank, near the Bohai Sea coastline. We defined scenarios based on three levels of water stress: drought, sufficient water, and flooding. The potential annual value loss in the drought scenario was 3.60×10^8 Yuan, versus 2.78×10^8 Yuan in the flooding scenario. The minimum loss (with sufficient water) was 2.06×10^8 Yuan. The wetland's soil water content should therefore be managed to protect the vegetation and minimize the ecological risks (and associated ecosystem service value losses) caused by water stress. Our approach provides a tool for assessing the potential loss of ecosystem services and functions and for calculating ecological compensation payments for wetland damage.

1. Introduction

Water is the most important environmental factor in wetland ecosystems. The magnitude and the temporal and spatial distribution of drought, flooding, and water quantity and quality affect the growth of wetland vegetation, a range of ecological processes, and the ecosystem services and functions. For China's Yellow River Delta wetland, which has experienced strong impacts from a combination of human activities and global climate change in recent decades, water scarcities in the downstream reaches of the Yellow River, including complete cessation of the river's flow in some years, have occurred frequently. As a result, the wetland's vegetation faces serious ecological risks, including shrinkage of the wetland area, a potentially severe loss of biodiversity, and declining biodiversity.

Most previous researchers in the Yellow River Delta focused on changes in the landscape pattern [1], the evapo-transpirational characteristics of the wetland vegetation [2], valuation of ecosystem services and functions [3], the ecological risk created by pollutants [4], assessments of environmental flows and ecological restoration technologies [5]. The importance of water to wetland ecosystems has been discussed at different spatial scales: at a regional landscape scale, for the effects of water depth on changes in landscape types [6,7]; at the community scale, for the influence of water content on the composition, diversity, and richness of species [8–10]; at individual species scales, for the influence of soil water content on the seed bank, population density, and height and biomass [9,11,12]; and at the physiological scale, for the effect of moisture content on nutrient contents and enzyme activity of plants and the soil [12–14]. However, little attention has been paid in the literature to the ecosystem services and functions and to the potential loss of these values as a result of water stress.

In this paper, we will focus on the ecological risks to wetland vegetation in Yellow River Delta caused by water stress, as well as the values of ecosystem services and functions and potential loss of these values for wetland vegetation under the ecological risks created by water stress. Based on previous results by our research group [15], we estimated the quantities and economic values of ecosystem services and functions related to the wetland vegetation, and quantified the potential loss of ecosystem services and functions caused by water stress. The results provide a

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valuable reference that can guide the calculation of eco-compensation payments or help hydrological managers to revise water allocations to ensure the preservation and sustainable management of the Yellow River Delta's wetland ecosystems.

2. Study area

2.1. Study site

The Yellow River Delta (37°35′N–38°12′N, 118°33′E–119°20′E), is one of the world's most active deltas. It is located in northeastern Shandong Province, on the southwestern shore of the Bohai Sea. The delta is ecologically important because of the vulnerability, rarity, and international importance of its native vegetation. The region has a temperate, semi-humid, continental monsoon climate. The average annual temperature is 12.1 °C. There are 196 frost-free days per year. The annual precipitation averages 551.6 mm, of which 70% falls during the summer, and the average annual pan evaporation is 1962 mm. The vegetation cover averages about 35% throughout the delta.

2.2. Types of wetland vegetation and their spatial distribution

We performed field surveys at 13 sample points distributed randomly through the study area. Each sample plot was 30 × 30 m, and we counted all plants in each plot. Our field samples and surveys in the Yellow River Delta wetland showed that *Phragmites australis* is the most common wetland plant species, followed by *Suaeda salsa* and *Tamarix chinensis*. Fig. 1 shows the vegetation frequency (the proportion of the sample plots that contained a given species).

We used data from the China–Brazil Earth Resources Satellite on 13 July 2008 as the original remote-sensing image data, and extracted the high tide line, so that our analysis only included parts of the delta that were not flooded permanently or diurnally by seawater) by combining automatic extraction with visual interpretation. In the data processing, we used geomorphological and biological features (such as the sediment characteristics and vegetation distribution) from field surveys to improve the interpretation accuracy. We used the supervised classification module of the ENVI software (http://www.exelisvis.com/ProductsServices/ENVI/ENVI.aspx) to classify the vegetation and calculate its area. Based on this analysis, *P. australis*, *T. chinensis*, and *S. salsa* covered

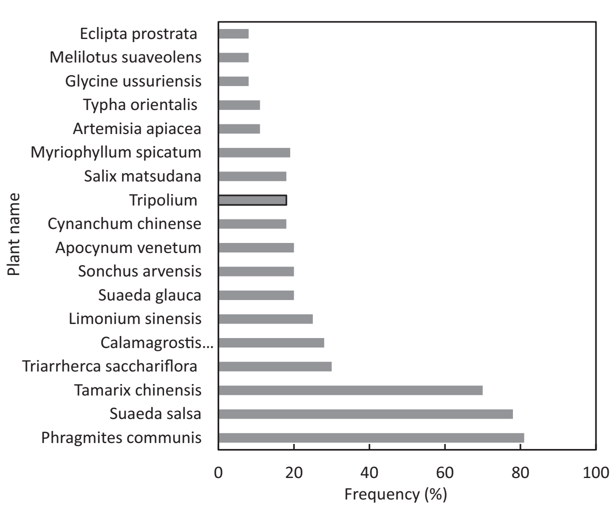

Fig. 1. Frequency of the most common plant species (total for all sampling sites).

48.24, 68.12, and 72.36 km^2, respectively. Their spatial distribution is shown in Fig. 2.

As shown in Fig. 2, *P. australis* was mainly distributed north of the Yellow River in its central to upstream reaches, but a small amount was distributed along both sides of the Yellow River in the lower reaches, in areas where the soil water content was higher. *T. chinensis* was found along both sides of the Yellow River, but mostly along the central to downstream reaches; it covered a longer distance along the river than *P. australis*. *S. salsa* was most abundant close to the Bohai Sea, particularly along the northern bank of the river and stretching from the central reaches to the mouth of the river, but a small amount was distributed along the southern bank of the Yellow River estuary, close to Laizhou Bay.

3. Methods and materials

3.1. Field sample sites and study design

Based on previous studies by Xiao et al. [16] in our study area, a suitable scale for our plant study was 30 × 30 m, so we used stratified sampling to select 13 sampling sites (each 30 × 30 m) in each of the upper, central, and lower reaches of the Yellow River, for our investigation of the plant nutrient element and soil water contents. Our field study was carried out in the spring, summer, and autumn (from April to October) in 2008, because all of the plants in these wetlands are dead or dormant during the winter and do not resume growth until April. We also installed a neutron probe access tube at each of the 13 sites to measure the soil water content at 10-cm intervals to a depth of 150 cm every 10 days. Qin et al. [15] provide details of the soil samples used to determine water and element contents.

3.2. Dominant ecosystem services and functions in the Yellow River Delta wetland

In this paper, we focused on the ecological risk to plants in the Yellow River Delta wetland caused by water stress, and the potential magnitude and value of the loss of ecosystem services and functions that resulted from this stress. In our assessment of the ecosystem services and functions, we selected indicators that are typically used in the literature on this subject, that were easy to calculate using available data, and that were able to reflect the effects of water stress; as a result, we chose biomass production, nutrient cycling, climate regulation, and plant diversity as the main ecosystem services and functions. Table 1 summarizes the valuation methods used to quantify the loss of ecosystem services and functions caused by water stress.

In this paper, we assessed both the quantity and the monetary value of each ecosystem service and function to quantify the potential loss.

3.3. Methods used to calculate the loss of ecosystem services and functions

3.3.1. Loss of biomass production

Material production refers to the products derived from the wetland ecosystem that can enter the market for exchange, including all the plant and animal products. In this paper, we focused on the loss of the plant-related biomass production, which is directly influenced by water stress. (We made this choice because reliable data on animal products is not available for our study area.) We focused on only the three most dominant species because these species covered the largest area of the wetlands and each was present in more than 70% of the sample plots. The most important plant is *P. australis*, which is a suitable raw material for industrial paper