The behavior of birds digging pits and foraging in the degraded coastal wetland promotes the restoration of vegetation

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ABSTRACT

Birds are a very important part of the coastal wetland ecosystem, and they are also ecosystem engineers who can affect the abiotic environment and biological processes through their own behavior. Understanding the ecosystem engineering effect of birds in the coastal wetland ecosystem plays an important role in the ecological restoration of coastal wetlands. Through field investigation, the effects of pit digging and foraging behavior of coastal birds led by Grus grus and Anas poecilorhyncha on the topography and soil environmental physical and chemical indicators in the vegetation degradation area were studied, so as to promote the restoration of Suaeda salsa vegetation. The results showed that birds’ digging and foraging behavior in the degraded vegetation area changed the micro topography and soil environment in the degraded area, resulting in a significant decrease in soil hardness and soil salinity, while soil moisture content and soil carbon and nitrogen nutrition index were significantly higher than those in the degraded flat area without the influence of birds; in addition, the pit micro terrain environment improved by bird activities can significantly improve the seed retention, seedling colonization and adult survival of Suaeda salsa, and effectively promote the restoration of Suaeda salsa in the vegetation degradation area. Inspired by the change of microtopography by birds to promote vegetation restoration, it is proposed that we can try to artificially simulate and transform the microtopography environment, and promote the vegetation restoration in the degraded area of coastal wetlands through human intervention, which has important guiding significance for the ecological restoration of coastal wetlands.

Keywords: Coastal Wetland; Birds; Foraging Behavior; Pit Microtopography; Vegetation Restoration; Promoting Effect

1. Introduction

In the ecosystem. Some organisms that have a certain impact on the abiotic environment of the ecosystem through their own biological disturbance process, and then directly or indirectly affect the composition of other organisms and key biological processes are usually referred to as ecosystem engineers[1-3]. A series of ecological effects of ecosystem engineers on ecosystem environment have been widely concerned and studied by many scholars at home and abroad[4,5]. In the natural ecosystem, the creatures that fond of digging are generally ecosystem engineers, such as crocodiles in rivers and lakes[6], mud crabs in tidal flats[5,7,8], ants in forests and other systems[9,10], rats in grassland areas[11,12], and so on. Many birds are also ecosystem engineers. Studies have shown that some birds’ nests can be reused by other organisms
after being abandoned\textsuperscript{[13]}. However, there are few reports on how birds affect the environment and other biological activities through excavation behavior as ecosystem engineers. Birds of various species are an important part of the coastal wetland ecosystem and can affect the key processes of the coastal wetland ecosystem. Many studies have shown that birds dig pits on the tidal flat through their beaks and claws in the coastal wetland to find benthic animals (nereis succenea, caenorhabditis elegans, snails, etc.) for feeding\textsuperscript{[14,15]}, which will leave many large and small holes on the tidal flat and affect the micro terrain environment of the tidal flat. A large number of studies have shown that the change of micro terrain structure in the ecosystem can affect the change of soil environmental indicators\textsuperscript{[5,16-18]}, as well as the seed retention\textsuperscript{[19,20]}, seedling planting\textsuperscript{[21-23]} and even the change of vegetation pattern\textsuperscript{[24–28]}. However, it is still unclear whether the foraging behavior of birds in coastal wetlands can have an impact on tidal flat vegetation.

Under the background of climate change, human activities have intensified the degradation of coastal wetland vegetation in the Yellow River Delta\textsuperscript{[29-31]}. However, some birds living in the coastal wetland of the Yellow River Delta can inadvertently change the micro terrain structure of the degraded area under the action of digging pits and foraging, which may affect the vegetation pattern of the coastal wetland. This paper explores whether the ecosystem engineering effect of bird digging and foraging activities can guide the vegetation restoration of coastal wetlands and promote the vegetation restoration effect in degraded areas of coastal wetlands. Through the field investigation of field observation and sampling analysis, this paper aims to reveal the effect of bird digging and foraging behavior in the coastal wetland of the Yellow River Delta on the transformation of the topography of the intertidal vegetation degradation area, its impact on soil environmental indicators, and its promotion on the vegetation restoration of Suaeda salsa. The behavior of birds foraging through digging pits in the degraded vegetation area was specifically studied, and the pit micro terrain area built by birds was compared with the degraded flat micro terrain area. The main comparisons were as follows: (1) the difference of average seed retention during seed propagation in winter; (2) the difference of the average planting amount of seedlings in spring; (3) the difference of average adult survival in summer; (4) the physical and chemical indexes of soil environment include the differences of soil hardness, salinity, moisture content, pH, organic carbon content, inorganic carbon content, total carbon content and total nitrogen content. It is expected to provide some enlightenment for coastal wetland vegetation restoration.

2. Research methods and data sources

2.1 Overview of the study area

The study area is located in a representative salt marsh area (37°46′N, 119°09′E) in the Yellow River Delta National Nature Reserve in Shandong Province. The study area (Figure 1) belongs to the temperate and monsoon climate, with four distinct seasons: spring, summer, autumn and winter. The annual average precipitation is 537.3 mm, and the annual average temperature is 12.8 °C\textsuperscript{[32]}, which is affected by irregular semidiurnal tides\textsuperscript{[33]}. Suaeda salsa is a typical native species in the Yellow River Estuary salt marsh wetland, which belongs to annual herb. Under the joint influence of climate change and human activities, there are many large degraded areas in Suaeda salsa vegetation community. Except for some benthic animals (nematodes, sand silkworms, etc.) living underground, there are few vegetation and other animals. The land is exposed, and even a salt pan is gradually formed. However, many birds, such as Grus and Anas poecilorhyncha, often appear in the degraded areas of Suaeda salsa in some salt lands. They dig holes with their beaks and claws to find under- ground benthic animals for foraging activities, thus forming many sunken holes (average diameter is about 15–30 cm, average depth is about 5–10 cm; Figure 2c and Figure 2d), changing the micro terrain environment of the degraded areas, thus, it is conducive to the restoration of vegetation in degraded areas.
In this study, a typical degraded area where birds often dig pits for food (Figure 1) was selected in the intertidal zone of the coastal salt marsh wetland of the Yellow River Estuary to carry out field investigation based on field observation and sampling analysis.

2.2 Research methods

2.2.1 Field investigation

In November 2017, many newly formed sunken pits were found in a large degraded area of the survey sample area. There are many bird footprints, feces and feathers on the edge of the pits (Figure 2c, Figure 2d). It is speculated that some birds may have dug pits here for food. Therefore, an area with dense pits was selected, and two infrared cameras were set up for image and video shooting (10 consecutive days of shooting in November 2017 and January 2018 respectively), so as to explore the causes of pits. The shooting of the
infrared camera verified our hypothesis. A group of Grus came here almost every morning at 6:40–7:40 (when the sun just rose) during the two shooting periods to dig holes with their beaks and claws to find benthic animals (nematodes, sand silkworms, etc.) for foraging activities (Figure 2a). In addition, a few spotted billed ducks occasionally come here to dig pits for food (Figure 2b), thus forming these pits and changing the microtopography of local degraded areas.

Figure 3. Photographs of foraging-associated hollows of birds intercepting seeds of Suaeda salsa in winter (a, b), promoting seedling establishment of Suaeda salsa in spring (c, d), and promoting plant survival of Suaeda salsa (e, f).

In order to test whether the pit microtopography changed by bird foraging activities has played a certain role in promoting the recovery of Suaeda salsa vegetation in the degraded area, this study first tallied the seeds of Suaeda salsa intercepted on the surface of 42 pits in the infrared camera shooting area in January 2018 (winter seed transmission period) (Figure 3a and Figure 3b), at the same time, the number of seeds in the degraded flat microtopography area near each pit that has not been changed by birds is counted in the same area. Through comparison, the promoting effect of the pit microtopography changed by birds’ foraging activities on the seed interception of Suaeda salsa vegetation is analyzed. Secondly, in May 2018 (spring seedling growth period), the seedlings growing in the same 42 pits were counted one by one (Figure 3c, Figure 3d). At the same time, the number of seedlings in the degraded flat microtopography area near each pit that was not changed by birds was tal-
lied. Through comparison, it was analyzed that the pit microtopography changed by birds’ foraging activities could indeed promote the colonization of Suaeda salsa seedlings. In addition, in August 2018 (summer adult growth period), the study tallied the adults that finally survived in the same 42 pits one by one (Figure 3e and Figure 3f), and counted the number of adults in the same area in the degraded flat microtopography area near each pit that was not changed by birds. Through comparison, it is analyzed that the pit microtopography changed by bird foraging activities can indeed promote the survival of Suaeda salsa seedlings to adults and vegetation restoration.

Experiments were carried out to test that the pit microtopography changed by bird foraging activities has an important impact on the physical and chemical characteristics of the soil environment in the tidal flat degradation area, and then the change of the soil environment plays a key role in the germination of vegetation seeds, the colonization and survival of seedlings. In January 2018 and May 2018, soil collectors (ring knives) were used to collect soil in the pit microtopography changed by bird foraging activities and on the unchanged degraded flat microtopography. Five duplicate samples were collected in each period and each different microtopography, a total of 20 soil samples. The collected soil samples are immediately sealed in hermetic bags and taken to the laboratory to determine the physical and chemical indicators such as soil moisture content, salinity, pH, organic carbon content, inorganic carbon content, total carbon content and total nitrogen content. The soil hardness in two different microtopography was measured with in situ soil hardness meter (SHM-22) in the field.

The soil samples brought back to the laboratory are first weighed by the balance to obtain the soil fresh weight index. Then, put the soil sample into an aluminum box and dry it in a 60 °C drying oven for more than 72 hours, and ensure that all the moisture in the soil is dried. Take out the dried soil and weigh it again with a balance to obtain the dry weight of the soil. The soil moisture content is obtained by subtracting the difference between the soil fresh weight and the dry weight and dividing it by the soil dry weight. After grinding and sieving the dried soil, weigh 8 g, put it in a centrifuge tube and mix it with 40 ml of deionized water (at 1:5)[32], and then shake the centrifuge tube for more than 30 minutes to fully mix the deionized water with the soil sample. After the soil sample is fully precipitated for a period of time, the soil salinity and soil pH are measured by the soil salinometer (JENCO 3010M) and the pH meter (HANNA HI 8424) respectively. The total carbon content and total nitrogen content of the soil after drying and grinding were measured by the element analyzer (Vario El, Germany); titrate and acidify the dried and ground soil with 1 mol/L dilute hydrochloric acid solution to remove all inorganic carbon, then dry, grind and screen the acidified soil samples again, and then use the element analyzer (Vario El, Germany) to determine the organic carbon content of the treated soil samples; the inorganic carbon content is obtained by subtracting the organic carbon content from the total soil carbon content.

2.2.2 Data processing and analysis

Before data analysis, Kolmogorov-Smirnov test is used to test the normal distribution of the data, and log data conversion is carried out for some data that do not conform to the normal distribution. Then One-Way ANOVA was used to analyze the significance of seed retention, seedling colonization, adult survival, soil hardness, water content, salinity, pH, organic carbon content, inorganic carbon content, total carbon content, total nitrogen content and other physical and chemical indicators in the pit microtopography with changes in bird foraging activities and the degraded flat microtopography with the same area nearby that was not affected by birds. All significant One-Way ANOVA were operated by SPSS 22.0 software.

3. Result analysis

3.1 The pit microtopography created by bird activities promotes seed retention, seedling colonization and survival of vegetation

It is found that in January 2018 (winter seed propagation period), the pit microtopography created by bird activities in the vegetation degradation
area can effectively intercept the seeds of Suaeda salsa (Figure 3a and Figure 3b). The average seed retention in each pit is about 31.00 ± 4.24 seeds, significantly higher than that in the degraded flat microtopography area with the same area as the pit and not changed by birds, which is about 1.19 ± 0.36 seeds (P < 0.001, Figure 4).

In May 2018 (spring seedling growth period), the pit microtopography created by bird activities in the vegetation degradation area can effectively promote the colonization of Suaeda salsa seedlings (Figure 3c and Figure 3d). The average seedling colonization in each pit is about 7.69 ± 1.22 plants, significantly higher than the average seedling colonization in the degraded flat microtopography area with the same area as the pit, which is not changed by birds (P < 0.001, Figure 4).

The survey also found that in August 2018 (summer adult growth period), the pit microtopography created by bird activities in the vegetation degradation area can effectively promote the survival of Suaeda salsa seedlings to adult-plants (Figure 3e and Figure 3f). The average adult survival in each pit is about 3.95 ± 0.59 plants, which was significantly higher than the average adult survival 0 of the degraded flat microtopography area with the same area as the pit near each pit, which was not changed by birds (P < 0.001, Figure 4).

2.2 The pit microtopography created by bird activities improves the physical and chemical characteristics of the soil environment

The pits created by birds’ foraging behavior affect the change of microtopography in the degraded vegetation area, and then they can affect the change of physical and chemical indicators of soil environment. They play an important role in promoting water increase, reducing soil hardness, reducing soil salinity, and promoting carbon and nitrogen nutrition indicators, which can further prove that the dimples microtopography of birds’ activity can effectively promote the restoration of Suaeda salsa vegetation. Through two sampling surveys and analysis in January 2018 and May 2018, it is found that there are significant differences in some basic physical indicators of soil environment between the pit microtopography created by bird activities and the degraded flat microtopography area that has not been changed by birds (Figure 5). Among them, the soil hardness in the pit microtopography created by bird activities in both periods was significantly lower than that in the degraded flat microtopography that was not changed by birds (P < 0.001, Figure 5a). In both periods, the soil moisture content in the pit microtopography created by bird activities was significantly higher than that in the degraded flat microtopography that was not changed by birds (P < 0.001, Figure 5b). In both periods, the soil salinity in the pit microtopography created by bird activities was significantly lower than that in the degraded...
flat microtopography that was not changed by birds ($P < 0.001$, Figure 5c). There was no significant difference in soil pH between the pit microtopography created by bird activities and the degraded flat microtopography that was not changed by birds in the two periods ($P_{201801} = 0.199, P_{201805} = 0.119$).

However, as for the average value, the soil pH in the pit microtopography created by bird activities in the two periods was slightly lower than that in the degraded flat microtopography that was not changed by birds (Figure 5d).

Figure 5. Comparison of basic physical indicators of edaphic environment between foraging-associated hollows of birds and degraded flat microtopography areas.
Note: *** means $P < 0.001$, and no mark means $P > 0.05$.

Figure 6. Comparison of nutrient indicators of edaphic environment between foraging-associated hollows of birds and degraded flat microtopography areas.
Note: ** indicates $P < 0.01$, * indicates $P < 0.05$, and no mark indicates $P > 0.05$. 
Through two sampling surveys and analysis in January 2018 and May 2018, it is found that there is a significant difference in carbon and nitrogen nutrition indicators of some soil environments between the pit microtopography created by bird activities and the degraded flat microtopography area that has not been changed by birds (Figure 6). In the two periods, the soil organic carbon content in the pit microtopography created by bird activities was significantly higher than that in the degraded flat microtopography that was not changed by birds ($P < 0.01$, Figure 6a). In both periods, the content of soil inorganic carbon in the pit microtopography created by bird activities was significantly higher than that in the degraded flat microtopography that was not changed by birds ($P < 0.05$, Figure 6b). In both periods, the total carbon content of soil in the pit microtopography created by bird activities was significantly higher than that in the degraded flat microtopography that was not changed by birds ($P < 0.01$, Figure 6c). In both periods, the soil total nitrogen content in the pit microtopography created by bird activities was significantly higher than that in the degraded flat microtopography that was not changed by birds ($P < 0.01$, Figure 6d).

4. Conclusion and discussion

This study shows that the pit digging and foraging behavior of birds in the degraded coastal wetland vegetation area of the Yellow River Delta can create an obvious pit microtopography, while compared with the flat microtopography in the degraded area not affected by birds, the creation of pit microtopography has significantly changed the physical and chemical indicators in the microenvironment, mainly manifested in the significant reduction of soil salinity and soil hardness, and the significant increase of soil moisture content, organic carbon content, inorganic carbon content, total carbon content and total nitrogen content; in addition, the pit microtopography can also effectively intercept the seeds of Suaeda salsa, and more appropriate environmental conditions can also promote the germination of seeds, the colonization of seedlings and the survival of adults, so as to effectively promote the restoration of Suaeda salsa vegetation in the degraded area. A large number of studies have shown that many birds dig pits on the tidal flats through their beaks and claws to look for benthic animals (bombyx mori, nematodes, snails, etc.) for foraging activities in the coastal wetlands[14,15]. However, there are few studies on the changes in the physical and chemical properties of soil microtopography and the impact on plant growth caused by birds’ foraging behavior. The common ones are studies on the changes of soil physical and chemical properties caused by burrowing behavior of crabs, rodents and other burrowing organisms and their effects on plant growth[5,8,11,34].

It is found that the pit microtopography built by birds can preserve certain moisture in a short time after tide, which makes the soil moisture content in these pit microtopography significantly higher than that in the degraded flat microtopography not affected by birds. Existing studies have also shown that pit microtopography will store more water and improve soil moisture content[35,36]. At the same time, due to the increase of soil moisture content, this study shows that the soil salinity in the pit microtopography created by bird activities is also significantly lower than that in the degraded flat microtopography, which is consistent with previous studies[35,37]. Bird digging has a certain loosening effect on the originally compact soil. In addition, the soaking effect of moisture after tide has significantly reduced the soil hardness in the pit microtopography, which is significantly lower than the flat microtopography without bird interference. Many studies have also introduced that some digging activities of animals can reduce the hardness of soil by promoting the enhancement of soil permeability and the increasing the proportion of coarse particles[38,39], which is consistent with the conclusion of this study. In addition, this study also shows that the pit microtopography created by bird activities does not significantly change the soil pH, and some studies also show that animal excavation does not change the soil pH[37], which is consistent with the results of this study. At the same time, it is also found that the pits formed by birds can also intercept many vegetation debris, and birds themselves will also produce certain feces while foraging,
which can promote the content of organic and inorganic carbon and nitrogen nutrition indicators in the pit micro terrain, and then promote the later growth of vegetation.

The research shows that in the intertidal zone where the coastal wetland vegetation is degraded, the pit micro terrain created by bird foraging activities can effectively intercept the seeds of Suaeda salsa brought by tidal transmission, so that the seeds of Suaeda salsa can be retained in the degraded area. Many studies have also shown that in various ecosystems, the concave convex micro terrain structure can be used as a trap to retain the seeds of vegetation\cite{19,20}. At the same time, the pit microtopography also provides a good microenvironment for seed germination and seedling colonization of Suaeda salsa. As discussed above, lower hardness and salinity, higher water content, and higher carbon and nitrogen nutrition content can promote the germination of vegetation seeds and the colonization and survival of seedlings. Existing studies have also proved that\cite{21,22,35}.

Therefore, the ecosystem engineering effect caused by this digging and foraging behavior of coastal birds has improved the soil micro terrain environment in the degraded area of coastal salt marsh wetland vegetation to a certain extent, and increased the seed retention and seedling colonization of vegetation, thus promoting the restoration of vegetation. Some studies have pointed out that the key and core content of wetland restoration is to promote the colonization and restoration of wetland primary vegetation\cite{40}. Therefore, it can be applied to the ecological restoration of the coastal salt marsh wetland environment according to the promotion of the pit microtopography created by bird activities to the Suaeda salsa vegetation, that is, for the plain land area with degraded Suaeda salsa vegetation, it can imitate the pit digging and foraging behavior of birds, and improve the ecological environment of the coastal wetland degraded area through manual excavation of suitable pit microtopography, so as to promote the colonization and restoration of Suaeda salsa vegetation. A large number of studies have shown that scientific and reasonable adjustment and management of soil underlying surface and land use mode in combination with regional geological and geomorphic environmental characteristics can promote the restoration of wetland soil hydrological conditions, organic matter content and vegetation ecosystem\cite{41-44}. The survey found that the size of microtopography created by birds’ digging and foraging behavior had no significant difference on the number of planted seedlings, and the size difference of microtopography created by birds was not very large. It is proposed that the artificially transformed microtopography can simulate the average size of microtopography created by birds’ digging and foraging behavior in natural state, that is, the average diameter is about 15–30 cm, and the average depth is about 5–10 cm, which can effectively restore vegetation. In addition, after artificially simulating and reconstructing the micro terrain in the degraded area to restore vegetation, it can create a better habitat for vegetation, birds and other organisms, promote the number and diversity of benthic animals in the soil, so as to further attract more birds to come here for feeding, and effectively restore the ecological balance of the whole degraded area. This paper has certain guiding significance for the ecological restoration of coastal salt marsh wetland in the Yellow River Delta.

Conflict of interest

The authors declared no conflict of interest.

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