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Multiple gradient effects on spatial distribution of island soil microbial biomass

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ABSTRACT

Soil microbial biomass (SMB) rapidly responds to the environment and can function as an important indicator for monitoring archipelago ecological vulnerability. An archipelago is featured by distinct and unique gradients between and within islands. The multiple gradient effects on the island ecosystem are worth exploring. We established a multiple gradient system comprising natural, human, and ecological gradients in island and site scales. The natural gradients consist of island area, shape, and distance to mainland in island scale, and terrain and distance to shoreline in site scale; the human gradients include population and exploitation in island scale, and distance to hardened ground in site scale; and the ecological gradients are composed of community type, biomass, biodiversity, and soil physical-chemical properties in site scale. SMB, including SMB carbon (SMBC), SMB nitrogen (SMBN), and SMB phosphorus (SMBP), was used to verify the multiple gradient effects on the island ecosystem, and the northern Miaodao Archipelago in North China was selected as the study area. Results revealed that SMB exhibited distinct spatial heterogeneities. SMBC was sensitive to the natural and human gradients in both scales; SMBN was influenced by parts of natural, human, and ecological gradients in both scales; and SMBP did not show regular changes along the gradients in island scale, yet responded sensitively to the ecological gradients in site scale. The multiple gradient system is unique and fundamental in the spatial heterogeneities of the island ecosystem, and fully revealing the multiple gradient effects is essential for reasonable island conservation and exploitation.

1. Introduction

Soil microbial biomass (SMB) is an active part in soil organic matter and a source of soil available nutrients [1]. SMB carbon (SMBC), SMB nitrogen (SMBN), and SMB phosphorus (SMBP) are the main components of SMB, which serve as links in the material circulation among pedosphere, lithosphere, atmosphere, hydrosphere, and biosphere [2,3] and are significant for soil organic matter formation and nutrient transformation [4]. SMB is influenced by complex factors and is sensitive to ecosystem change [3,5]. SMB can rapidly respond to different environmental conditions, and changes in SMB will result in the turnover of soil element [6]. Therefore, SMB is always considered to be a sensitive and effective indicator of soil ecosystem change [7,8].

Islands are natural storage pools for biodiversity and important platforms for ocean conservation and exploitation [9,10]. Island ecosystems have obvious vulnerability due to their unique natural conditions and various external disturbances [10–12]. The soil is the base of islands and bears the survival and development of biological communities [13]. Thus, SMB could function as an important indicator for monitoring island ecological vulnerability. However, studies on island SMB cannot presently address its importance. An archipelago is an aggregation of neighboring islands; it is the common form of islands in China. As a special geographic entity, an archipelago is featured by distinct and unique gradients. The islands in an archipelago are similar in geological background and are interrelated with one another; however, considerable differences in the areas, shapes, distances to mainland, and terrain may exist [14]; thus, clear natural gradients are generated. Human activities on islands are heterogeneously distributed,

Abbreviations: SMB, soil microbial biomass; SMBC, SMB carbon; SMBN, SMB nitrogen; SMBP, SMB phosphorus; TJI, Tuoji Island; DQI, Daqin Island; XQI, Xiaoqin Island; NHCI, Nanhuangcheng Island; BHCI, Beihuangcheng Island; SI, shape index; EI, exploitation index; Al, altitude; Sl, slope; As, aspect; DTM, distance to mainland; DTS, distance to shoreline; DTH, distance to hardened ground; B, biomass; H', Shannon–Wiener index; E, Pielou index; MC, soil moisture content; Sa, salinity; TP, total phosphorus; TK, total potassium; TN, total nitrogen; TC, total carbon; TOC, total organic carbon

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thereby resulting in variations in exploitation intensity between and within islands [15] and the formation of human gradients. Ecological characteristics, such as community types, biomass [16], biodiversity [17], and soil physical and chemical properties [13], regularly change under the influences of natural and human conditions. Consequently, the ecological gradients are also distinct. The preceding gradients mentioned have effects in island and site scales. Therefore, the multiple gradients between and within islands in an archipelago are prominent. Dose and how the multiple gradients affect the island ecosystem are worth exploring. Island SMB, which is sensitive to the environment and essential to an island ecosystem, is highly suitable to verify the multiple gradient effects on an archipelago.

We established an archipelago multiple gradient system influencing island SMB based on the typical features of an archipelago ecosystem. The northern Miaodao Archipelago, a typical archipelago in North China, was selected as the study area. The SMB spatial distributions in island and site scales were analyzed through field investigation and remote sensing, and the multiple gradient effects on the SMB spatial distribution were discussed.

2. Material and methods

2.1. Study area

The northern Miaodao Archipelago is located north of the Shandong Peninsula and at the juncture of the Yellow and Bohai Seas, which is the location of the Changdao County in Shandong Province, China (Fig. 1). Five inhabited islands, namely Tuoji Island (TJI), Daqin Island (DQI), Xiaoqin Island (XQI), Nanhuangcheng Island (NHCI), and Beihuangcheng Island (BHCI) constitute the main body of the northern Miaodao Archipelago. The study area is located in the central Bohai Strait; the distribution of islands is dispersed in a chain form; the areas, shapes, and distances to the mainland significantly differ among different islands. The study area is in the East Asian monsoon region. The terrain is undulating, with mountains lying in a roughly south–north direction. The areas of TJI, DQI, XQI, NHCI, and BHCI are 7.22, 6.48, 1.18, 1.89, and 2.69 km^2, respectively; and the highest altitudes are 198.9, 202.4, 148.9, 100.9, and 155.4 m, respectively. The native forests are poor due to the atrocious natural condition, and the current forests are dominantly planted with *Pinus thunbergii* and *Robinia pseudoacacia* as the dominant species of coniferous and broad-leaf forests, respectively. Only several woody species occur. However, varieties of widely distributed native herbaceous plants exist [17]. Brown soil covers the largest area at a thickness of approximately 30 cm. The soil quality is poor with a significant amount of gravel [17]. Human activities on the northern Miaodao Archipelago have been increasing in recent years. Aquaculture, fishing, and tourism are the main industries; houses, public facilities, roads, docks, farmland, and plantation have rendered land cover types complicated and various [13]. Furthermore, different islands vary in exploitation type and intensity. TJI is the largest island in the northern Miaodao Archipelago and has the most population. DQI is famous for its high-quality kelp; large-scale kelp cultivation leads to the intensification of island exploitation, and sunning grounds are widely distributed. NHCI is rich in rare seafood and thus is in a good economic condition. XQI and BHCI are in a low level of development. The gross domestic products of TJI, DQI, XQI, NHCI, and BHCI are 826, 598, 122, 231, and 320 million Yuan (125, 90, 18, 35, and 48 million Dollars), respectively, and their populations are 8400, 4374, 890, 926, and 2228 people, respectively.

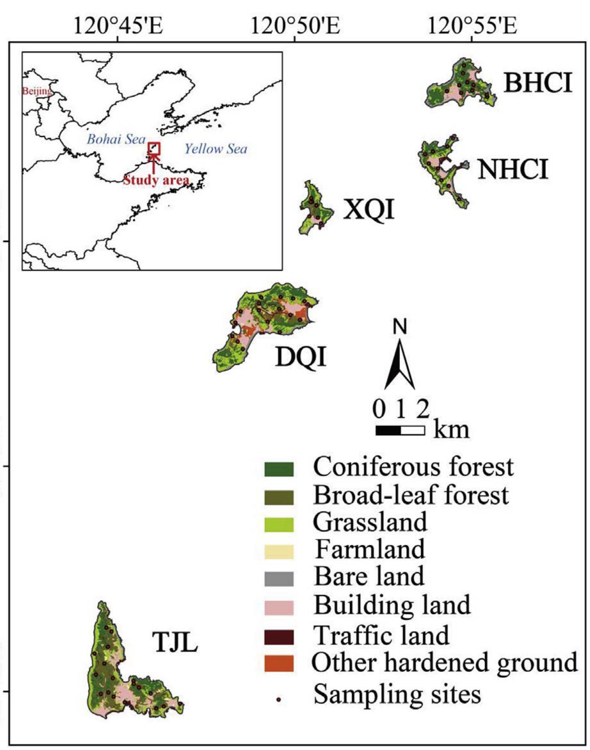

Fig. 1. Location, land cover types and sampling sites of the study area: TJI: Tuoji Island; DQI: Daqin Island; XQI: Xiaoqin Island; NHCI: Nanhuangcheng Island; BHCI: Beihuangcheng Island. The different land cover types are coniferous forest, grassland, broad-leaf forest, building land, bare land, other hardened grounds, traffic land, and farmland in descending order of areas. A total of 60 sampling sites were conducted in 2015.

2.2. Data sources

Plant community investigation and sampling were conducted in September 2015. A total of 60 sampling sites with 20 × 20 m size were set according to island areas, spatial distribution, community types, and terrain (Fig. 1). The latitude, longitude, altitude (Al), slope (Sl), and aspect (As) of each sampling site were measured using a handheld Global Positioning System device and an electronic compass. Plant data, including species, abundance, height, and coverage in tree, shrub, and herb layers were recorded. The diameter at breast height (DBH) of trees with DBH ≥ 3 cm was measured. Soil samples were collected, and the soil physical-chemical properties were then measured. Moisture content (MC) was measured using an oven drying method; pH was measured using a potentiometric method; salinity (Sa) was measured using a gravimetric method; total phosphorus (TP) was measured using an ultraviolet spectrophotometric method; total potassium (TK) was measured using an atomic absorption spectrophotometric method; total nitrogen (TN) and total carbon (TC) were measured using an elemental analyzer; and total organic carbon (TOC) was measured using a potassium dichromate oxidation method. SMBC, SMBN, and SMBP were determined by a chloroform fumigation extraction method.

The remote-sensing images from the Systeme Probatoire d'Observation de la Terre (SPOT) 6 satellite on September 3, 2015 (the spatial resolutions of panchromatic and multispectral bands are 1.5 m and 6.0 m, respectively) were adopted. Image cutting, radiometric calibration, and band fusion of the SPOT 6 satellite data were conducted using ENVI 5.3. The outlines of islands were extracted, and the area, perimeter, distance to mainland (DTM) of each island, and distance to island shoreline (DTS) of each site were obtained. Land cover types were derived by visual interpretation based on remote sensing data and modified through field investigation; they were divided into coniferous forest, broad-leaf forest, grassland, farmland, bare land, building land, traffic land, and other hardened grounds (squares, sunning ground, and so on) (Fig. 1).

2.3. Spatial distribution of SMB

The SMBC, SMBN, and SMBP were analyzed in island and site scales, and their spatial distributions were exhibited. In site scale, the