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# Archipelagic landscape patterns and their ecological effects in multiple scales

Yuan Chi[a,b], Honghua Shi[a,b,*], Wei Zheng[a], Enkang Wang[a]

[a] The First Institute of Oceanography, State Oceanic Administration, Qingdao, Shandong Province, 266061, PR China
[b] Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, Qingdao, Shandong Province, 266061, PR China

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ABSTRACT

An archipelago is a unique geographic complex with distinct vulnerability to disturbances in coastal areas. The natural features, increasing human activities and their spatial heterogeneities in the archipelago result in complex landscape patterns and ecological effects, which makes the archipelago natural laboratory for landscape ecology study in multiple scales. The particular spatial scales of landscape, island and grid were followed to reveal the comprehensive status, influencing factors and ecological effects of archipelagic landscape patterns, and the Miaodao Archipelago in North China was selected as the study area. Landscape pattern indices (LPIs) in different scales were analysed based on field investigation and geographic information system. Ecological response indicators (ERIs) responding to archipelagic landscape patterns were identified and the relationships between LPIs and ERIs, including land surface temperature (LST), net primary productivity (NPP), plant diversity and soil property, were discussed. Results indicated that plantation, grassland and building land occupied the largest areas in the landscape scale and ERIs significantly differed among different landscape types. In the island scale, some of LPIs regularly changed with the changes in island area, distance to the mainland, population and GDP, yet ERIs were generally insensitive to landscape pattern. In the grid scale, LPIs showed distinct spatial heterogeneities and were affected by altitude and slope; LST, NPP and soil fertility were affected by landscape types, fragmentation, edge effect and shape complexity, whereas plant diversity and soil moisture were mainly influenced by landscape types. The landscape patterns exhibited specific characteristics in different scales, and their ecological effects were closely related to the scales. Island area, distance to the mainland, terrain and human activity were fundamental, the most relevant, limiting and main driving factors of archipelagic landscape patterns, respectively.

## 1. Introduction

Landscape pattern is the outcome of the joint effects of natural and anthropogenic factors on geographical space and is increasingly affected by human activities (Chen et al., 2013). Landscape pattern also significantly influences ecosystem structures, functions and processes (Cook, 2002; Strohbach and Haase, 2012; Ramalho et al., 2014). Scale is the lens that focuses the ecological relationships which is an essential factor in landscape ecology studies (Levin, 1992; Mcgarigal et al., 2016). Landscape pattern and its ecological effects vary significantly in different scales (Wu and Loucks, 1995; Duelli, 1997; Grafius et al., 2016). Spatial scale is usually considered a certain resolution in a form with unified sizes and regular boundaries (Xu et al., 2004). However, the size is determined based on the experience, such as common coarse (25 m) and fine (5 m) spatial resolutions (Grafius et al., 2016). As such, size determination possesses subjectivity and lacks geographic significance. An archipelago is an aggregation of neighbouring islands; it is advantageous for landscape ecology studies in multiple scales. Islands are natural storage pools for biodiversity and important platforms for ocean conservation and exploitation (Jupiter et al., 2014; Chi et al., 2015a). Island ecosystems exhibit distinct vulnerability and sensitivity because of the unique positions, limited areas, clear isolations, complex natural disturbances and increasing human disturbances (Chi et al., 2015a). Island exploitation area and intensity have been increased and enhanced in recent years; as a result, natural landscapes are separated, artificial landscapes are increasing and thus landscape patterns are markedly changed (Wang et al., 2008; Tzanopoulos and Vogiatzakis, 2011). In an archipelago, basic features, such as areas, shapes, distances to mainland and terrain conditions, differ among islands (Vogiatzakis et al., 2008). Human activities are also spatially different. As such,

* Corresponding author. The First Institute of Oceanography, State Oceanic Administration; Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, No.6, Xianxialing Road, Qingdao, Shandong Province, 266061, PR China.
*E-mail address:* shihonghuafio@163.com (H. Shi).

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landscape patterns are complex and heterogeneous. With these features, the archipelago can be utilised as a natural laboratory for landscape pattern research in multiple scales (Losos and Ricklefs, 2010), including landscape, island and grid scales. Landscape scale is conducted in the entire archipelago; island scale focuses on different islands in an archipelago; grid scale is the minimum scale representing spatial heterogeneity. Landscape and island scales are naturally determined by the archipelagic characteristics, and grid scale is set to satisfy the spatial heterogeneity requirements.

Landscape patterns affect island ecosystems in many ways. Specific ecological response indicators (ERIs) to landscape patterns can be found in island ecosystems. In general, the ecological effects of landscape patterns involve various elements, including atmosphere, water, ecosystem service and heat island (Pauleit et al., 2005; Lovell and Johnston, 2009; Chen et al., 2013). In island ecosystems, pollutant emissions caused by landscape pattern changes are little and surface runoff is scarce. Thus, atmospheric and aquatic environmental responses to landscape patterns are not obvious. Changes in archipelagic landscape patterns can be directly observed in the shrinking and separation of natural landscape, enlargement of artificial landscape areas, increase in landscape types and strengthening of landscape pattern heterogeneity. Land surface temperature (LST) is the most immediate physical parameter responding to human activities; it greatly affects the soil water, vegetation growth and energy cycle of island ecosystem and differs spatially because of the increasing island urbanisation (Li and Becker, 1993; Qin and Karnieli, 2001; Chi et al., 2015b). Net primary productivity (NPP) is an important factor to identify the carbon source/sink characteristics; it indicates the vitality of island ecosystem and sensitively responds to different land use types (Field et al., 1998; Chi et al., 2015c). Plant diversity helps maintain and regulate the ecosystem material recycling and energy flow, and represents the ecosystem stability (Hooper et al., 2005; Tilman et al., 2006; Cardinale et al., 2006). It suffers from human disturbances and was increasingly influenced by landscape fragmentation (Ramalho et al., 2014; Chi et al., 2016). The soil functions as the base of islands and provides places and nutrients for biological community (Schlesinger, 1991; Ouyang et al., 1999; Chi et al., 2017). Most islands in China are bed rock islands with eroded hills as the main geomorphic type (Chi et al., 2017). Thus, the soil moisture and fertility are always low and constrain the plant growth; they are also greatly affected by landscape patterns (Fu et al., 1999) and can be selected as the indicators of soil property. LST, NPP, plant diversity and soil property are considered the ERIs of islands; they involve thermal characteristics (LST), vegetation growth condition and ecosystem vitality (NPP), species composition and ecosystem stability (plant diversity), and water-nutrient supply and ecosystem base (soil property), which comprehensively represent the various aspects of island ecosystem. The relationships between landscape patterns and ERIs should be analysed, one by one, to identify the ecological effects of archipelagic landscape patterns.

The Miaodao Archipelago in North China was selected as the study area. The landscape patterns were analysed in terms of landscape, island and grid scales through field investigations and geographic information system. ERIs, including LST, NPP, plant diversity and soil property, and their relationships with landscape patterns were then discussed. Our study aimed to reveal the variation characteristics of island ecosystems affected by complex natural and anthropogenic factors and to provide additional insights into landscape patterns in different scales.

## 2. Materials and methods

### 2.1. Study areas

The Miaodao Archipelago is located north of the Shandong Peninsula and at the juncture of the Yellow and Bohai Seas (Fig. 1). Ten inhabited islands constitute the majority of the Miaodao Archipelago, surrounded by numerous uninhabited islands with small areas. The study area is the location of the Changdao National Nature Reserve for island ecosystem conservation. It is in the warm temperate monsoon climate zone, with the average annual temperature of 12.0 °C and rainfall of 537 mm. The terrain is undulating with the highest altitude of about 202 m. The study area is also the location of Changdao County in Shandong Province of China. In 2015, the gross domestic product (GDP) of the county was 6.243 billion Yuan (942.7 million Dollars) and the GDP per capita was 147,300 Yuan (22,242.3 Dollars), which was at a high level in China (Xu and Zhang, 2013). At the end of 2015, the total population was 42,183, of which the urban population was 21,658.

The Miaodao Archipelago is the typical island area in North China. The islands have similar geological background and are composed of bed rocks, whereas differ in areas, shapes, distances to the mainland, terrain and other natural conditions. Meanwhile, the rapid developments of fishery and tourism result in the increasing exploitation on the islands; houses, public facilities, roads, docks, farmland and plantation make the landscape types diverse and the human exploitation activity shows differences between and within the islands. Therefore, the landscape pattern exhibits obvious spatial heterogeneity under the joint influences of natural and socioeconomic conditions, and the influencing factors and ecological effects of the landscape pattern are complicated. All aforementioned conditions make the Miaodao Archipelago possess high suitability for landscape pattern study in different scales.

The ten inhabited islands were used as the study objects with a total island area of 50.62 $km^2$ and can be divided into five southern and five northern islands according to their locations. The five southern islands consist of Nanchangshan Island (NCSI), Beichangshan Island (BCSI), Miaodao Island (MI), Xiaoheishan Island (XHSI) and Daheishan Island (DHSI), which are near the mainland with concentrated distribution, and of which NCSI is the demographic, economic and cultural centre of Changdao County. The five northern islands include Tuoji Island (TJI), Daqin Island (DQI), Xiaoqin Island (XQI), Nanhuangcheng Island (NHCI) and Beihuangcheng Island (BHCI), which are far from the mainland with dispersed distribution (Fig. 1).

### 2.2. Data sources

Remote sensing: The panchromatic remote sensing image in 2013 of WorldView-1 satellite, which was launched by DigitalGlobe at 2007, with a spatial resolution of 0.5 m, was collected, and island area, distances to the mainland and other basic information were obtained through ArcGIS10.0. Then, the landscape types were derived by visual interpretation based on the remote sensing data and modified through field investigation on July 2014; they were divided into coniferous forest, broad-leaf forest, grassland, farmland, bare land, building land, traffic land and other hardened ground (Fig. 2). Among the landscape types, coniferous forest and broad-leaf forest are plantations with *Pinus thunbergii* and *Robinia pseudoacacia* as the dominant species, respectively; grassland is the native herbaceous community; farmland is covered by seasonal crops, such as soybean and corn; bare land includes the bare rock and other uncovered lands in the shore and inner island; building land is occupied by houses and public facilities; traffic land includes dock in the shore and the road inside the islands. Other hardened ground is the compacted ground after artificial pavement expect for building land and traffic land, such as square and sunning grounds. The multispectral remote sensing images from LANDSAT 8 satellite, which was launched by NASA at 2013 with an operational land imager and a thermal infrared sensor, in five phases (April 21, August 11 and November 15 in 2013; January 2 and April 24 in 2014) were adopted, and the normalised difference vegetation index (NDVI) values of different seasons were extracted through the cutting of images, radiometric calibration and bands calculation. The version two of Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (Aster GDEM) with a resolution of 30 m, which was