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Spatial distribution patterns of *Sargassum horneri* in the coastal waters of the Ma'an Archipelago

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ABSTRACT

Seaweed beds are a nearshore marine ecosystem composed of macroalgae and other marine organisms. In recent years, soil erosion, pollution, and other land-based mechanisms have severely reduced nearshore algal populations, particularly in areas influenced by the outflow of the Yangtze and Qiantang rivers. The Ma'an Archipelago is located in the estuary of the Yangtze and Qiantang rivers in the East China Sea. Although the archipelago is relatively distant from the shore, algal populations there have decreased significantly in recent years. The reasons for this decline are unknown, owing to an absence of data on macroalgal spatial distribution in seaweed beds and of long-term monitoring. Numerous environmental factors, operating at different scales, are likely to contribute to the abundance and distribution of macroalgae in seaweed beds. Therefore, it is important to study the beds across spatial scales to understand the ecological factors influencing the beds' presence and decline. During September 2014 and May 2015, we investigated the distribution of *Sargassum horneri* in germling and adult stages at 12 sites on three islands (Zhongkui, Lvhua, and Gouqi) around the Ma'an Archipelago. Our results showed that: (1) on a whole-archipelago scale, *S. horneri* density was highest around Zhongkui Island, and lowest around Lvhua Island. Adult plant lengths showed the opposite trend. The ratio of average densities around the three islands was 1 (Lvhua): 3.8 (Gouqi): 13.8 (Zhongkui) at the germling stage, and changed to 1:1.8:4 at the adult stage. (2) At the individual-site scale, wave exposure may explain why *S. horneri* density is highest in southeastern sites and lowest in northwestern ones. Around Zhongkui Island, *S. horneri* grew in turbulent conditions, was significantly affected by wave motion, and suffered a high mortality rate between the seedling and adult stages. (3) Within site scale, *S. horneri* was distributed over a considerably wider depth range around Zhongkui Island than around Lvhua or Gouqi islands. Adult *S. horneri* was most abundant at 2-m depth. Wave action apparently controlled the upper limit of *S. horneri* bathymetric distribution, whereas the lower limit depended on sedimentation and light availability.

1. Introduction

Seaweed beds are a nearshore marine ecosystem composed of macroalgae and other marine organisms that mainly live on hard bottoms. In recent years, soil erosion, pollution, and other land-based mechanisms have severely influenced nearshore seawater transparence and reduced nearshore algal populations [1], particularly in areas influenced by the outflow of the Yangtze and Qiantang Rivers, where algal populations are scarce. It is reported that waste and polluted water emissions in the Yangtze River have increased from 9.5 billion tonnes in 1970 to 33.3 billion tonnes in 2009 [2]. Influenced by Yangtze-originating water, nearshore seawater has low salinity, and high levels of nutrient salt and suspended substances [3], which all have a negative effect on the distribution and growth of macroalgae [4,5]. According to recent dive surveys, there are only a few patches of seaweed beds, mostly *S. horneri* [6,7], growing in small areas around the offshore islands in the Yangtze and Qiantang estuary, such as in the Ma'an Archipelago and the Zhongjieshan Archipelago. Although these islands are distant from the shore, human activities have affected them, resulting in significantly decreased populations of macroalgae [6]. According to an earlier survey, seaweed populations used to be abundant in these areas [8]. Owing to a lack of long-term monitoring data on seaweed bed populations, it is hard to know the distribution of seaweed beds around the Ma'an Archipelago prior to the pollution. Many surveys on seaweed beds have been carried out; however, we need first-hand observation data to verify the damage that the polluted marine environment causes to nearshore seaweed beds. In China, the situation is further complicated by a lack of dive surveys on the distribution of seaweed beds, which makes it hard to determine the reasons for their decline.

The distribution of seaweed beds is influenced by many factors [9], including the scale on which it is measured, which complicates its study. On a global scale, seaweed beds are mainly found in cool coastal zones, as well as around partial tropical and subtropical coasts [10].

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Temperature and daylight are the most important factors affecting seaweed beds in general [11]. On a regional scale, nutritive salt, water current, sedimentation, pollution are the main drivers of distribution [12–15], whereas on a site-level scale, wave and attaching substratum features are important [16,17]. On a within-site scale, the depth of the water is the most effective parameter predicting the structure of macroalgal communities [18]. Therefore, it is important to study the formation mechanisms of seaweed beds on multiple scales, which also enables determination of the main impact factor.

We investigated the distribution of *S. horneri* in germling and adult stages around the Ma'an Archipelago, across different scales, at Lvhua Island, Gouqi Island, and Zhongkui Island. We also tested seawater salinity and turbidity around these three islands. By comparing the density and length of *S. horneri* across depths and directions, we can determine how the distribution of *S. horneri* was established and the causes of its decline. Thus, we can provide the basis for future protection and restoration of the beds.

2. Materials and methods

2.1. Study sites

The Ma'an Archipelago is located in the southeast of the Yangtze estuary, belonging to Shengsi country. It is the northernmost archipelago, consisting of 135 islands, including five islands of the Haijiao Archipelago and seven islands of the Langgang Archipelago. The archipelago spreads from northwest to the southeast; Lvhua Island lies in the northwest near the shore, Gouqi Island in the middle, and Zhongkui Island in the southeast near the open sea. The selected sites are far away from human disturbance. According to the experience of local people, the gentle reef slope areas were the best choice. Thus, we randomly selected 12 sites in four directions on the reef slopes around these three islands (Fig. 1).

2.2. Sampling methods

The research began in September 2014, when the distribution and growth of germlings was surveyed around the three islands. Sampling was carried out using self-contained underwater breathing apparatus. At each site, three transects were chosen, with each transect perpendicular to the shoreline. The first quadrat (30 cm × 30 cm) was chosen at the top boundary of where *S. horneri* was found. All of the *S. horneri* found within the quadrat was gathered in a sample bag. Then, a quadrat was placed downward 1 m from the previous site, and the *S. horneri* were gathered until no longer found. The gathered *S. horneri* specimens were counted and their lengths measured. Each site was located by GPS, and the tracking survey was carried out in May of the following year, which is the propagating season of *S. horneri*.

2.3. Measurement of environmental factors

Data on the distribution of *S. horneri* at different water depths were obtained from a dive computer (Mares Nemo Sport). The sample times were also recorded. Seawater salinity and turbidity were measured by a multifunctional water quality instrument (ALEC AAQ176), with each measurement conducted three times for each site.

2.4. Data analysis

Densities and lengths of *S. horneri* were analyzed with one-way analysis of variance tests using SPSS 13.0. Descriptive statistics compared the means ± standard error among treatments; p values of <0.05 were taken as significant). The average sea level according to the tidal table of Shengshan (2015) was taken as the standard level. The water depth was calculated at each sample site by a formula [19]. Research on the spatial distribution of *S. horneri* around the three islands used the mean sea level as the standard level, with pairwise tests applied for multiple comparisons between any pair of treatment groups at different water depths. As no *S. horneri* was found at water depths from 0 cm to 99 cm, the first treatment group was taken from 100 cm to 199 cm. Every group after this was measured at an increment of 1 m.

3. Result and analysis

3.1. Horizontal distribution patterns of S. horneri

The Ma'an Archipelago extends from the NW to the SE, with the three islands in order of increasing distance from the shore as: Lvhua

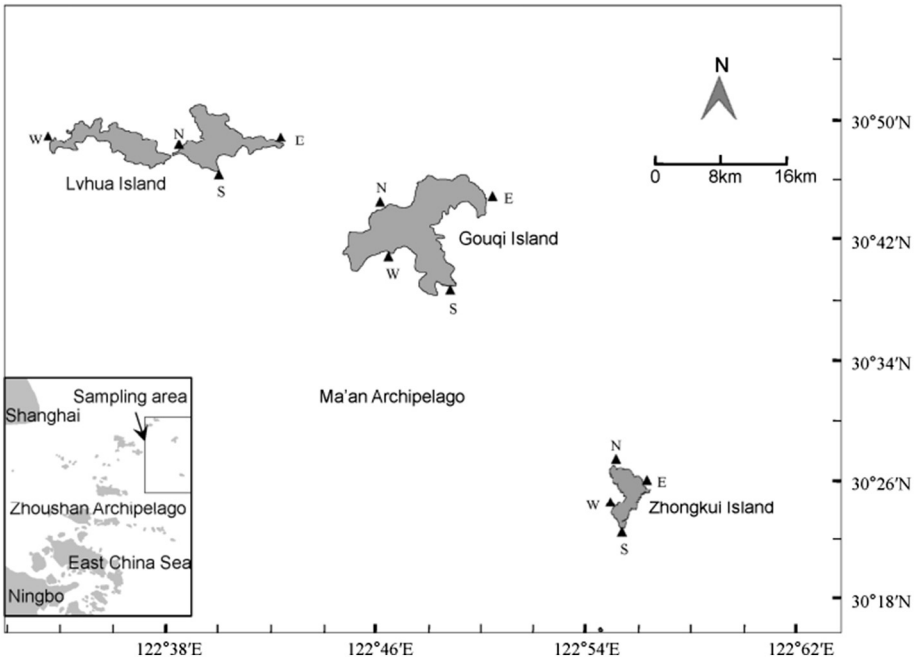

Fig. 1. Map of three islands showing the locations of the twelve study sites.