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# The effects of sediment on *Sargassum horneri* in the early life stages on rocky subtidal reefs

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A B S T R A C T

Sediment plays an important role in controlling the distribution of macroalgae. We examined the distribution of *Sargassum horneri* in the field considering the effect of sedimentation, and conducted sediment manipulation experiments to test the hypothesis that sedimentation affects the early settlement stages of *S. horneri*. Field samplings were conducted on rocky subtidal platforms off Gouqi Island, in Zhoushan Archipelago in the Eastern China Sea. Water depth and motion were also measured. Sediment traps and a suction pump were used to collect *in situ* sediment. In the laboratory, two experiments were conducted to test the effects of sediment cover on zygote attachment and germling survival, respectively. Attachment rate of *S. horneri* zygotes was reduced from 81.3% of the control group to 3.6% with a medium dusting of sediment (approx. 0.5 mm thickness), and 0% with a heavy dusting (approx. 0.7 mm thickness). For the germlings, 1.0% of survived when covered by medium (approx. 0.7 mm thickness) sediment coverage, whereas high coverage (approx. 1.8 mm thickness) caused 100% mortality. Our study showed: 1) in the field, distribution of *S. horneri* was negatively correlated with sediment amount, and *S. horneri* was always found abundant in sites with less sediment and intermediate water motion; 2) in laboratory-based experiments, small changes in the abundance of deposited sediment prevented zygote settlement; and 3) relatively small increases in settling sediment affected the survival of already settled zygotes/germlings. In conclusion, we found that sediment was an important driver of *S. horneri* distribution, especially during the early settlement stages.



## 1. Introduction

In recent decades, the destructive actions of humans in the coastal environment have caused an increase in sedimentation in nearshore waters, which has changed the structure and diversity of organisms found on rocky reefs (Airoldi, 2003). Species that can tolerate sediment survive to the exclusion of others, and as a consequence, they dominate the habitat (White et al., 2000; Terawaki et al., 2003). Conversely, species that cannot tolerate sediment die off (Airoldi, 1998).

The composition and amount of sediment on rocky coasts is extremely variable both spatially and temporally, making sedimentation effects difficult to study directly; sediment has numerous possible sources, and the distribution and dynamics of sediment particles are impacted by both environmental and biological processes (Fornos et al., 1992; Piazzi et al., 2005; Airoldi, 2003). Studies have included experimental tests of the effects of sediment on rocky coast organisms and assemblages (Marshall and McQuaid, 1989; Kendrick, 1991; Chapman and Fletcher, 2002). Physical and biological effects are likely to be synergistic, but the impacts they have on benthic communities are not the same and should be distinguished (Taylor and Littler, 1982).

Macroalgae are some of the most ecologically significant organisms that attach to rocky reefs, and they form one of the canonical ecosystems of nearshore waters. Most studies of sediments on rocky shores have noted the variable presence of sediments and their variable effects on algal assemblages (Littler et al., 1983;

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Stewart, 1983; Airoldi et al., 1996; Wernberg et al., 2005). For example, coarse sediment such as sand and gravel may scour surfaces, and abrade organismal tissues or remove organisms completely from a reef (Airoldi, 2000a). To assess the relationship between *Sargassum horneri* and sediment in the field, we examined the distribution of *S. horneri* and environmental factors on rocky subtidal platforms in the coastal waters off Gouqi Island, in Zhoushan Archipelago in the Eastern China Sea.

Many studies have shown that sediment can impact macroalgal distribution, especially during the early attachment stage of zygotes (Devinny and Volse, 1978; Arakawa and Matsuike, 1992; Vadas et al., 1992; Geange et al., 2014; Alestra and Schiel, 2015). In laboratory-based experiments, we examined the effects of sediment cover on the early settlement stages (zygote attachment and germling survival) of *S. horneri*.

The main objectives of this study were: 1) to quantify the relationships between water motion, the amount of sediment, and the distribution of *S. horneri*; 2) in the laboratory, to test the effects of different amounts of sediment on zygote attachment and germling survival of *S. horneri*; and 3) to consider the distribution of *S. horneri* in the context of field-derived estimates of sedimentation and our experimental results in the laboratory.

## 2. Materials and methods

### *2.1. Study sites and field samplings*

On 30 July 2012, field sampling was conducted around Gouqi Island, in the Zhoushan Archipelago in the East China Sea (30°42′–30°44′N, 122°44′–122°48′E, Fig. 1). Six accessible sites (240 cm deep) were chosen to represent a range of water motion and sedimentation conditions. In addition, a wave-sheltered site, S1, was chosen to assess the impact of water depth on the distribution of *S. horneri* based on its field situation, which was relatively stable and suitable for diving and sampling. Samples were taken at each study site (S1–S6) at 240 cm water depth, as well as four additional depths (340 cm, 440 cm, 540 cm, and 640 cm) at site S1.

The density of *S. horneri* was investigated by quadrat sampling using SCUBA. At each of the samplings, all visible individuals of *S. horneri* were recorded in each of eight randomly-placed 0.09 $m^2$ quadrats in the area around the sediment traps.

Water motion was gauged using the dissolution rate of plaster blocks, as described by Terrados and Duarte (2000). Three plaster blocks were placed near the sediment traps for each sample, and retrieved after 24 h. The weight lost from each block was measured after being dried at 55 °C for 5 days. The formula

$$\frac{\text{Weight loss}_{\text{field}}}{\text{Weight loss}_{\text{still sea water}}} \times \frac{\text{Exposure time}_{\text{field}}}{\text{Exposure time}_{\text{still seawater}}}$$

provides a dimensionless index that describes the intensity of water motion (Jokiel and Morrissey, 1993; Thompson and Glenn, 1994; Terrados and Duarte, 2000).

Sediment traps were used to estimate the short-term relative differences in sediment load among sites for the 14-day sampling period. We used a medium j-shaped tube (internal mouth diameter 5.5 cm, 82 cm long, with a length-to-mouth diameter ratio of 15) as described previously by Schiel et al. (2006). At each sampling site, three replicate traps were horizontally mounted at a height of 50 cm above the substratum, and firmly fastened to iron stands that were fixed by expansion bolts in holes drilled into the rocky reef. Sediment in the traps was collected 14 days later (on 13 August 2012).

We also used a suction pump to collect sediment at the same five depths of site S1, to compare with the corresponding trap-samples. At each depth, three 0.09 $m^2$ quadrats (30 cm × 30 cm) were set around the sediment traps. A suction pump (750 W) was used to collect sediment from the quadrats. The pipe of the pump intake was covered with a 3 mm sieve to prevent damage from coarse gravel.

Each sediment sample was carefully poured into a bucket, then sealed, and taken to the laboratory. Samples were kept still for 24 h, and sediment volumes were measured to calculate *in situ* thickness of sediment layers. Supernatant water was then carefully removed. To separate size fractions, sediment was poured through sieves of different hole sizes (30 μm–1.1 mm). The fractions were gently washed with distilled water to remove salt, and then dried for 72 h at 50 °C to measure dry weight.

### *2.2. Laboratory experiments: the effect of sediment on success and settlement of fucoid zygotes*

Sediment manipulation experiments were conducted to test the hypothesis that sedimentation affects the early settlement stages of *S. horneri*. Separate experiments were done for zygote attachment and germling survival. We used the natural sediment loads collected by suction pump at site S1. The collected sediment was filtered through a 1-mm sieve to remove large gravel and debris, and used as sediment slurry. Zygotes of *S. horneri* were obtained from cultured adults using a 100 μm sieve. Microscopic observation showed that most of zygotes were at the 64-cell stage, and capable of attaching well. A slurry of zygotes was made using 1 L *in situ*-filtered seawater and collected zygotes, with a final density of 1160 ind/mL (N = 5, SD = 18.7).

To test the effect of sediment on zygote attachment, we prepared five groups of cement plates (8 cm × 8 cm × 5 cm) with different amounts of sediment, where each group contained 4 replicates. Sediment slurry was evenly and softly sprayed on the plates of different volumes: None (control group), I, II, III, and IV, with thicknesses of 0 mm, 0.2 mm, 0.4 mm, 0.5 mm, and 0.7 mm, respectively, and sediment dry weights of 0 mg/$cm^2$, 3.5 mg/$cm^2$, 6.9 mg/$cm^2$, 10.5 mg/$cm^2$, and 14.0 mg/$cm^2$, respectively. After the sediment slurry, 1 mL of zygote slurry was sprayed evenly on each plate. The plates were randomly placed in a large seawater tank (900 cm × 80 cm × 60 cm). Seawater was slowly poured into the tank until the plates were totally submerged. After 3 days of culture, plates were gently lifted out of the tanks and all attached individuals were counted under a microscope.

A second experiment was conducted to test the effect of sediment on the survival of *S. horneri* germlings. Zygote slurry was sprayed on the cement plates as described above, and germlings attached to the plates were observed under the microscope after 7 days. Attached germlings were 1 week old, approximately 1 mm in length, and had a density of 916 individuals per 64 $cm^2$ on average (N = 4, SD = 13.6). Plates with even distribution of germlings were selected and randomly divided into six groups (each group with four replicate plates). The treatment groups were evenly sprayed with different volumes of sediment slurry: None (control group), I, II, III, IV, and V, with thicknesses of 0 mm, 0.2 mm, 0.4 mm, 0.7 mm, 1.5 mm, and 1.8 mm, respectively, and sediment dry weights of 0 mg/$cm^2$, 3.5 mg/$cm^2$, 6.9 mg/$cm^2$, 14.0 mg/$cm^2$, 27.9 mg/$cm^2$, and 34.9 mg/$cm^2$, respectively. After 7 days of culture, all living germlings on the plates were counted under the microscope.

### *2.3. Data analysis*

Data of *S. horneri* was transformed to individuals in terms of ind/$m^2$, and sedimentation was expressed in terms of thickness (mm). Percentages of sediment size fractions were analysed. Zygote attachment rates were calculated based on the average density of 1160 ind/mL; while germlings survival rates based on the average density of 916 individuals per 64 $cm^2$.