Development and Verification of Ecohabitat Chart based on Ecological Geotechnics

Développement et Vérification de Ecohabitat Diagramme ont basé sur Écologique Géotechnique

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ABSTRACT: By utilizing our new approach in Ecological Geotechnics, we performed series of controlled laboratory experiments on benthos-soil systems with six species of invertebrates that belonged to Arthropoda, Mollusca, and Annelida. The experimental results demonstrated that for each of the burrowing activities, there exist optimal, transitional and critical geoenvironmental conditions, which were found to differ considerably between species, body sizes and weights. On the basis of these results, we have constructed an ecohabitat chart which enables an interspecific comparison of the burrowing performances and capabilities of the diverse benthic fauna in light of the associated geoenvironments in the field. The results of integrated field observations and surveys at various natural and artificial intertidal flats further demonstrate the validity and effectiveness of the ecohabitat chart in not only evaluating but also predicting the linkage between the species distributions and the ensuing geoenvironments. Hence, the present findings, together with the developed chart will effectively contribute to a new horizon of the performance-based geoenvironmental assessment, design and management for the conservation and restoration of habitats with rich ecosystems in intertidal zones.

RÉSUMÉ : En utilisant notre nouvelle approche dans Écologique Géotechnique, nous avons exécuté série d'expériences de laboratoire sur les systèmes du benthos-sol avec six espèces d'invertébrés qui ont appartenu à Arthropoda, Mollusca et Annelida. Pour chacun des activités fouisseuses, là a existé des optimales, transitionnelles et critiques geoenvironmental conditions qui ont différé considérablement entre espèces, dimension du corps, et poids qui ont permis le développement d'un diagramme de l'ecohabitat. Ce diagramme a été validé à travers champ études de l'intertidal naturels et artificiels. Les conclusions contribueront à un nouvel horizon de du geoenvironmental performance-basée estimation et gestion pour la conservation et restauration d'habitats avec les écosystèmes riches dans les intertidal zones.

KEYWORDS: ecological geotechnics, geoenvironment, intertidal flat, ecosystem.

1 INTRODUCTION

Biodiversity in oceans has received increasing attentions in recent years, particularly following the COP10 initiative to conserve and restore the valuable ecological systems. Intertidal zones are the vital elements in the sustainability of estuarine and coastal environments since they foster rich natural ecosystems. Previous research in the fields of ecology and water science has been directed to understanding the diversity of ecosystems, their water purification functions and associated hydroenvironments. However, geoenvironments as habitats and their linkage with biological activity remain poorly understood, although their complete understanding is crucial to the conservation and restoration of habitats.

Recently, we developed an integrated continuous observation system that enables close inspection of the geoenvironmental dynamics that take place in the zones relevant to benthos diversity and applied it to intertidal flats (Sassa and Watabe, 2007). Through the combined use of field, experimental and theoretical investigations, we have found that the dynamics of suction associated with tide-induced groundwater level fluctuations play a substantial role in controlling the geophysical environments of habitats (Sassa and Watabe, 2007), and there is a close linkage between the waterfront geophysical environment and the ecology of intertidal flats (Sassa and Watabe, 2008; Kuwae et al., 2010; Sassa et al., 2011).

The paper reports our recent findings from such new cross-disciplinary research field which we call "Ecological Geotechnics" (Sassa and Watabe, 2009). Specifically, the present study aims to investigate systematically the burrowing performances and capabilities of diverse species that belong to Arthropoda, Mollusca, and Annelida, and to develop an ecohabitat chart by which to evaluate the interrelationships between suitable and critical geoenvironment among species. The validity of the ecohabitat chart is assessed in light of the results of integrated field observations and surveys of the waterfront geoenvironment and species distributions at various natural and artificial intertidal flats.

2 DEVELOPMENT OF ECOHABITAT CHART

For the purpose of the present study, we targeted diverse species such as bivalves, worms, crabs, shrimp and decapod crustacean and realized an integrated comparison of the burrowing performances though a range of controlled laboratory experiments of benthos-soil systems. For the materials, we used tidal flat soils as well as agar based on the study of Sassa & Watabe (2009). In the series of the experiments, we simulated and varied the vane shear strength according to the procedures described in Sassa & Watabe (2009), and investigated the burrowing responses of each of the six species used, for one hour period. In cases where burrowing was possible, an individual burrowed under the soil surface. In contrast, in cases where burrowing was impossible, the whole body remained on the soil surface. For the bivalves and shrimp, partial burrowing manifested, and thus in order to elucidate their burrowing capabilities, we examined their responses for six hour period. All of the individual species were collected from natural intertidal flats such as Banzu, Ena, Nojima and Furenko intertidal flats, and acclimated in a water tank for the period of one month under constant air and water temperatures. We used

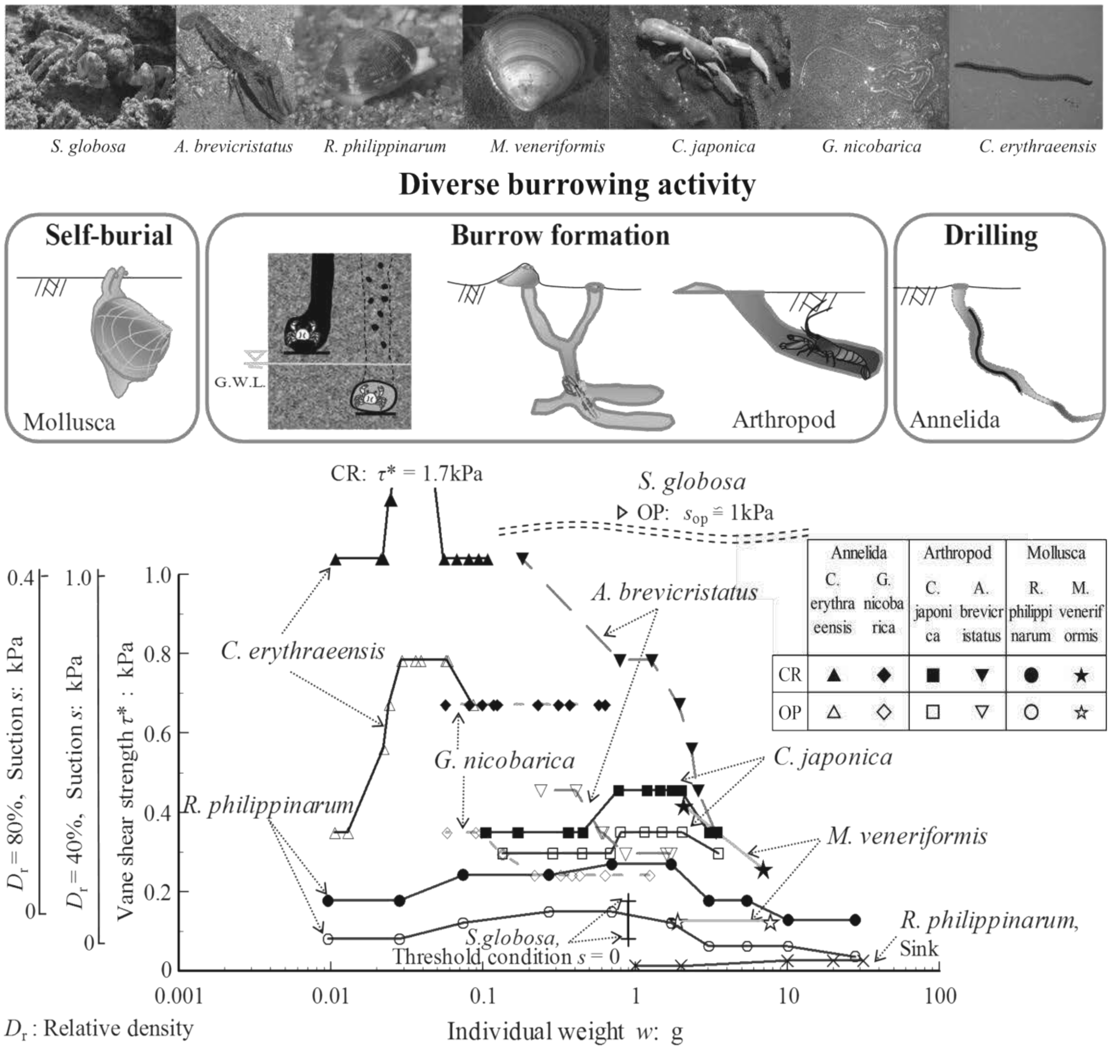

Figure 1. Ecohabitat chart and the interrelationships between optimal and critical geoenvironment among species in intertidal flats

a total of 835 individuals whose body sizes ranged from 2mm to 88mm and whose body weights ranged from 0.004g to 31.6g.

The experimental results are summarized in Fig. 1. This figure shows three burrowing regions, namely, an optimal region (below OP) where all individuals burrowed, a transitional region (between OP and CR) where burrowing success and failure mixed, and a critical region (above CR) where all individuals failed to burrow, in light of the vane shear strength. The associated suction ranges for the two different relative densities, 40% and 80%, were obtained on the basis of the calibration experiments of the tidal flat soils. The data are plotted for each species and growth stage as characterized by the individual weights. Note here that the threshold condition represents the situation where the sand bubbler crab cannot form burrows without suction. Figure 1 shows that for all the species and growth stages, there existed both suitable and critical conditions for burrowing, which differed considerably between species in a complex manner. This burrowing performance chart is named here the ecohabitat chart, which will be clarified in detail below.

3 VERIFICATION OF ECOHABITAT CHART

We performed field surveys at five natural and artificial intertidal flats located in Japan from 2009 to 2011. Specifically, we conducted integrated surveys of the geophysical environment and the species distributions during spring low tides at the Nojima intertidal flat in March 2009 and September 2010, at the Shirakawa intertidal flat in September 2009, at the Isumigawa intertidal flat in August 2009, at the Naha intertidal flat in June and December 2009 and February and September 2011, and at the Tokuyama artificial intertidal flat in September 2010 and June 2011. At each intertidal flat, we measured the spatial distributions of suction, groundwater level and vane shear strength, and collected undisturbed samples of surficial sediments of 50mm thickness, and subjected them to a series of laboratory soil tests to determine their grain size distributions, water content ratio *w*, specific gravity G_s, void ratio *e*, relative density D_r and the degree of saturation $S_r = G_s \cdot w/e$. At each location of the geophysical measurements described above, we took four core samples of 200mm diameter and 100mm thickness to obtain the density distributions (mean ± SE) of the two different bivalves of various growth stages, *R. philippinarum* (Manila clam) and *M. veneriformis* at the Shirakawa intertidal flat, and the burrow density distributions of the sand bubbler crab *S. globosa* and the decapod crustacean *C. japonica at* the Naha and Isumigawa intertidal flats, and measured and identified the species, individual densities and weights for each category of Arthropoda, Mollusca, and Annelida at the Tokuyama artificial intertidal flat. We compared the species distributions with the corresponding geophysical measurements obtained through these field surveys and laboratory tests, and analyzed them in light of the ecohabitat chart developed in this study.

At all the five natural and artificial intertidal flats, there

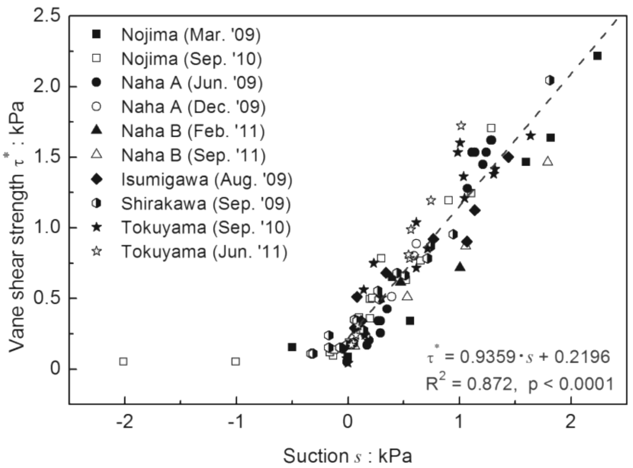

Figure 2. Relationship between suction and vane shear strength at five natural and artificial intertidal flats

was a strong correlation and unique interrelationship between suction and hardness of the surficial intertidal flat soils (Fig. 2). Indeed, the vane shear strength varied by a factor of 20–50 due to suction, that stemmed from the combined effects of suction development and suction-dynamics-induced cyclic elastoplastic soil compaction in the essentially saturated states (Sassa and Watabe, 2007). Such suction is found to be closely linked with the distributions of the various species as described below.

For the purpose of later discussion, the relationship between the shell lengths and wet weights of the two different bivalves, *R. philippinarum* (Manila clam) and *M. veneriformis* at the Shirakawa intertidal flat are shown in Fig. 3. We categorized adult and juvenile bivalves according to the shell length distributions in Fig. 4a. The individual densities of the juvenile and adult bivalves (mean ±SE) are plotted in Fig. 4b and c. The figure shows that for both Manila clam and *M. veneriformis,* the juveniles inhabited the area even where suction developed, but, the adults, particularly the adult Manila clams inhabited only the waterfront area where suction did not develop. Also, the peak density of the adult *M. veneriformis* manifested where the developed suctions were higher than those for the adult Manila clam. These field results are well consistent with the ecohabitat chart indicating the following. Namely, the burrowing capability of the Manila clam decreased considerably toward adult stages when the shell lengths exceeded 20mm corresponding to the wet weigths 1.5 to 2g in Fig. 3. This means that the adult Manila clam could not effectively burrow in denser soils as a consequence of the suction dynamics. Furthermore, the suitable geoenvironment for the adult *M. veneriformis* was above that for the adult Manila clam in the chart. This fact also conforms to the observed results.

Figure 5 shows the relationship between suction and burrow densities of the sand bubbler crab *S. globosa* and the decapod crustacean *C. japonica* at the Naha and Isumigawa intertidal flats. Both species inhabited the geoenvironment particular to each species, irrespective of the survey locations and periods. In fact, the individual densities increased markedly at suction equal to 1kPa for the *S. globosa*, and about 0.2kPa for the *C. japonica*. This observation conforms quantitatively to the ecohabitat chart showing that the suitable geoenvironment for *S. globosa* was well above that for *C. japonica*.

Figure 6 shows the relationship between suction and individual densities of Arthropoda, Mollusca, and Annelida at the Tokuyama artificial intertidal flat. The survey was conducted soon, one and half year, after the reclamation. It is seen that in the unsaturated region where suction exceeded the air-entry suction of the soils, the densities of all species declined, indicating the importance of water retention in soils for the survival of species. In the saturated region, the density of *C. erythraeensis* outnumbered the other species. This fact is also

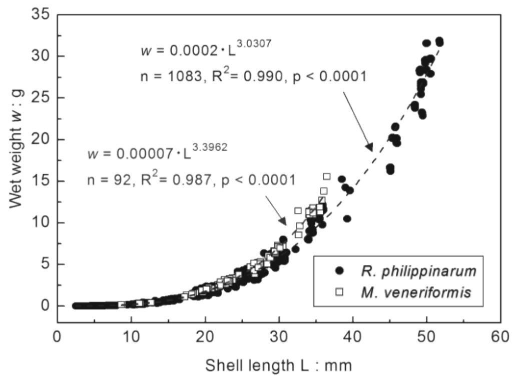

Figure 3. Relationships between shell length and wet weight of *R. philippinarum* and *M. veneriformis*

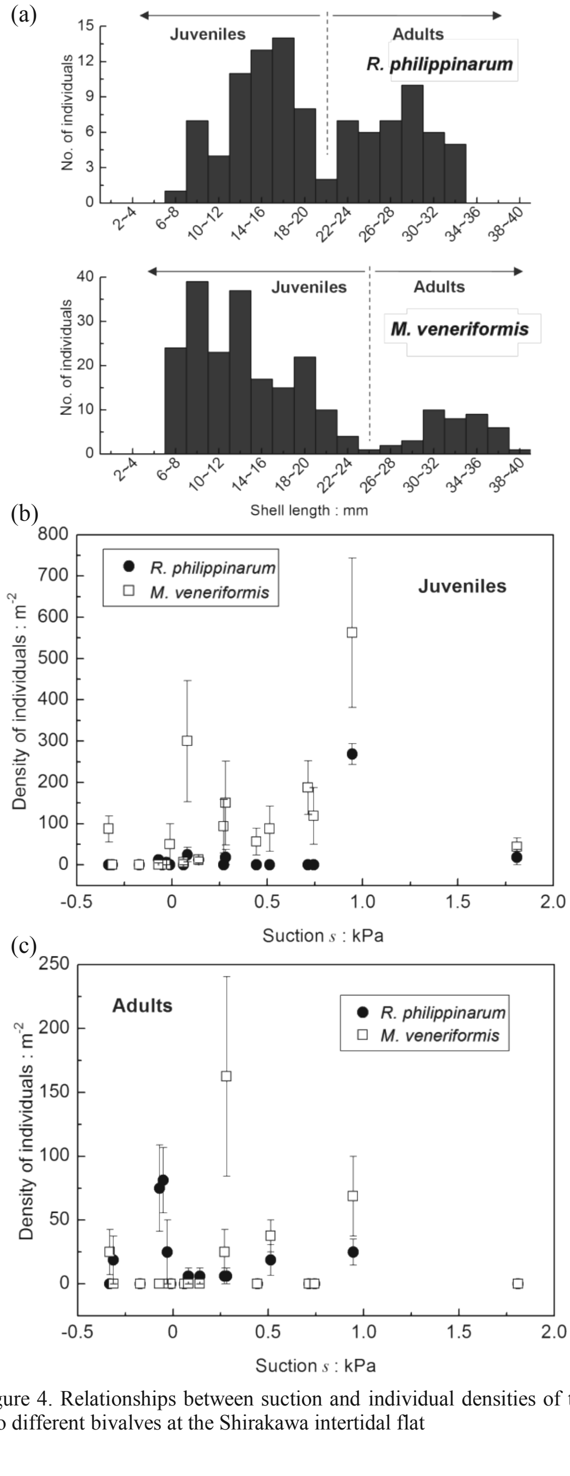

Figure 4. Relationships between suction and individual densities of the two different bivalves at the Shirakawa intertidal flat

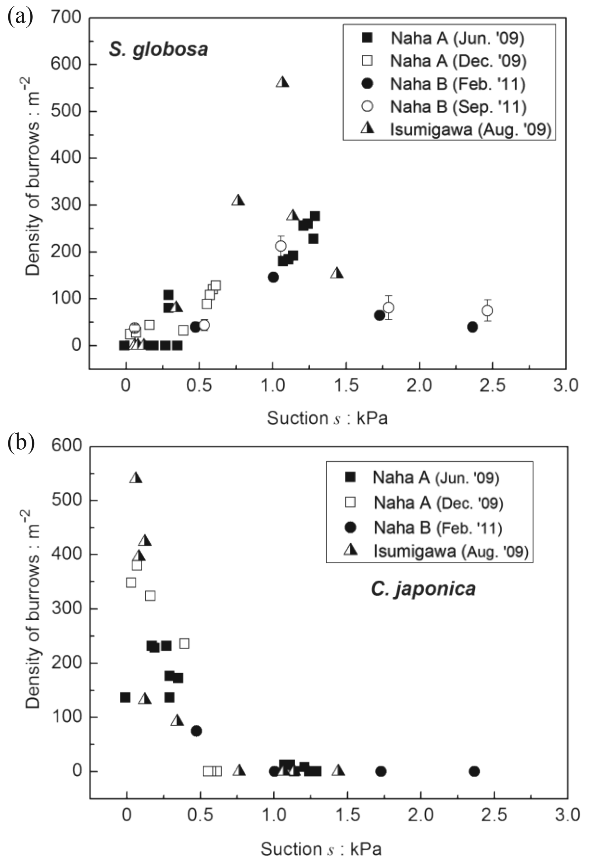

Figure 5. Relationships between suction and individual densities of the sand bubble crab and the decapod crustacean at three intertidal flats

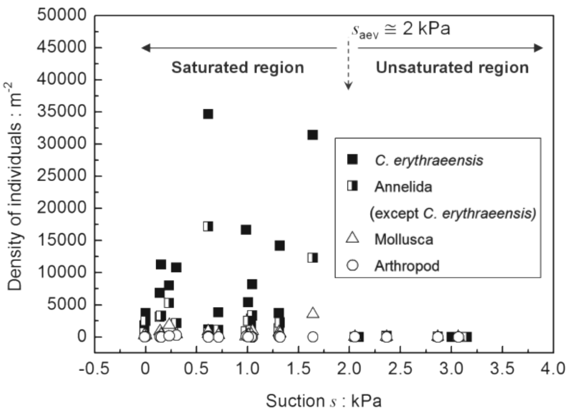

Figure 6. Relationships between suction and densities of Arthropoda, Mollusca, and Annelida at the Tokuyama artificial intertidal flat

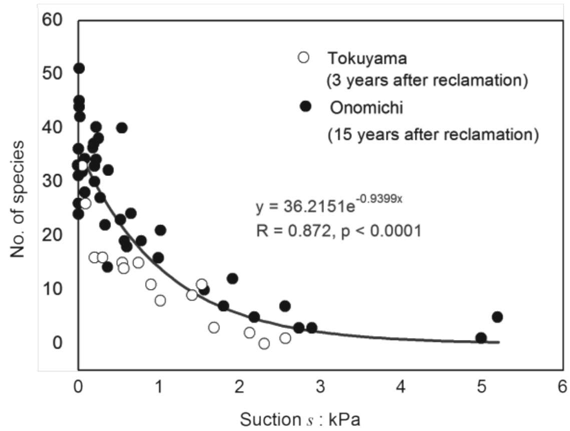

Figure 7. Relationships between suction and diversity of species at two different artificial intertidal flats

consistent with the ecohabitat chart showing that the burrowing capability of *C. erythraeensis* was markedly higher than other species and thereby exhibited the characteristics as the initial species inhabiting the reclaimed soils.

Figure 7 shows the relationship between suction and the number of species that was obtained three years after the reclamation at the Tokuyama artificial intertidal flat. For the purpose of comparison, the results of the field surveys conducted fifteen years after the reclamation at another artificial intertidal flat, the Onomichi flat, are also plotted in this figure. One can observe that there is a close correlation between the diversity of species and suction. This fact is in agreement with the ecohabitat chart demonstrating that the suction-induced geoenvironment governs the manifestation of suitable and critical conditions for the diverse species, and the number of species, which can adapt to a severer geoenvironment, decreases with increasing suction and shear strength. As such, these results indicate that the difference in the suitable and critical geoenvironment among species contributes significantly to the distributions of the diverse species inhabiting there.

4 CONCLUSION

In the present study, we investigated systematically the linkage between the waterfront geoenvironment and the burrowing activity of six species of invertebrates in intertidal flats through a series of controlled laboratory experiments on the benthos-soil systems. The experimental results elucidate for the first time that there exist both suitable and critical geoenvironmental conditions for the burrowing activities of the diverse species irrespective of burrowing types, growth stages and weights. On the basis of these results, we have developed an ecohabitat chart which reveals complex interrelationships between such suitable and critical geoenvironment among species.

In order to clarify the validity of the chart, we performed integrated field observations, surveys and analyses concerning the waterfront geoenvironment and the species distributions at five natural and artificial intertidal flats. The results demonstrate that the way and where the diverse species lived are well consistent with the ecohabitat chart developed in this study.

Overall, these results succeed not only in answering the fundamental question of why intertidal flats foster a complex ecosystem by the diverse species, from a view point of Ecological Geotechnics, but also establishing a new rational basis which can facilitate the conservation and restoration of habitats with rich natural ecosystems in intertidal zones.

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