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THE ENVIRONMENTAL PARAMETERS CONTROLLING THE HABITAT OF INVASIVE ALIEN SPECIES, *SPARTINA ALTERNIFLORA* IDENTIFIED BY PREDICTIVE MODELING

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ABSTRACT: *Spartina alterniflora* introduced worldwide has impacted local Japanese ecosystems. Then the management methods of the species are seriously required. In 2019, the invasion of the species was reported at Aichi Prefecture, Japan. The vegetation of the species was grown up to 449 m^2 for 5 years. However, the relationship between the habitation of the species and environmental factors remains unclear. Therefore, we made a habitat prediction model using GLM (general linear model) to define the environment of the *S. alterniflora* habitat of Aichi Pref., incorporating data in 2019. That measured population density, location, ignition loss of physical environmental data, pH, NaCl concentration and altitude over the sea level by us. Our analysis showed that the standardization parameter altitude over the sea level was the main effect in the predictive model (estimate 4.158) and had the greatest absolute value. And the Wald value is significantly large (42.426). Secondary the reciprocal relationship expression between the altitude and pH was high value, 1.007. The species likes the habitat that altitude is high and pH is 7.1-7.3. For the GLM, we made the distribution for the species, the reappearance is well done. Then the avoidance of the species expansion, the bank of the tidal area should erase the higher riverbed.

Keywords: General Linear Model, Habitation, Invasive species, Management of Invasive Species

1. INTRODUCTION

Smooth cordgrass, *Spartina alterniflora* was ordinally distributed at seashore at North America and the Gulf Coast of the Mexico. The species is a perennial plant at salt marsh and estuary. They occupied rapidly into the tidal zone and the environmental condition of the tidal zone has been changed by the species [1]. The vegetation of the species reduces the energy of the sea wave and helps stop the coastal erosion. In China and other countries planted the species that grew up in North Carolina, Georgia and Florida for the controlling the sea erosion [2-5]. An S. Q. *et al.* (2007) showed that introduced *S. alterniflora* in China was approximately 2.6 km^2 until 1985, and that it has increased more than 430 times after 15 years (1120 km^2), in 2000 [6].

Thus, rapid invasion showed significant adverse impacts on natural ecosystems, this species listed by Lows *et al.* (2000) among the 100 most hazardous invasive species in the world [7]. In 2008, the species was detected at Aichi Prefecture, Japan and next year at Kumamoto Prefecture. The rapid expansion of the species changed the tidal area, salt marsh and creek area in Aichi Prefecture. About 3 years later the creek was filled by the plant and the water stream was prevented and the creek is almost dry land. The Ministry of the Environment declared the species an invasive alien species (LAS) on the Invasive Alien Species Act of Japan in 2014 [8]. In Aichi Prefecture, the Ministry of Land, Infrastructure, Transport and Tourism, many companies and many volunteers removed the species from the salt marsh and creek from 2011 to 2013, then all the plant removed from this area. In 2018 the species was detected 50 km away from where *S. alterniflora* was previously discovered in Aichi Pref. From the Street View at Google map the invasion of the species was observed at the map in 2013. For 5 years the vegetation of the species has been widespread until 2018.

In order to prevent the invasion, it is necessary to monitor the invasion of the species, but it is impossible to do it because of the necessity to monitor a vast area along seashore. To conserve the local natural ecosystems we must detect rapidly in order to remove them with low cost. We, therefore, made a habitat prediction model using GLM (General linear models) to further define the environment of *S. alterniflora* habitat. The area of the invasion prediction is defined, we can easily find out the invasion of the species. In a protection plan of the salt marsh and tidal area ecosystem, analysis using GLM is carried out for relation about habitation density and environmental factors [9][10]. In this analysis, we considered the habitation restriction factors of the *S. alterniflora* in

Japan.

2. MATERIALS AND METHODS

2.1 The Second Level Headings

The place of the investigation was Horikawa river, located in center of Japan at Pacific Ocean side (Fig. 1). The creek is 1.08km for the agriculture drain. It has the gate to prevent sea water flood about 500m from the mouth of the river. The banks of the river are made of concrete brock that have higher river bed.

Fig.1 Map of research locality

2.2 Study Plant

Spartina alterniflora commonly known as smooth cordgrass or oyster grass, is a salt-tolerant perennial grass native to the Atlantic Coast of North America. It is also found on the Pacific Coast of the United States, where it is considered an invasive species. *Spartina* species are among the few salt marshes plants that have been introduced outside their native range for erosion control due to their abilities to colonize open areas, stabilize eroding shorelines, and reclaim land.

The species displays considerable genetic and genotypic diversity, which affects growth and morphology, and ecological functions [11]. In the low intertidal zone, *S. alterniflora* is often the dominant species because of its high tolerance of frequently flooding and hypoxia conditions. Very few species can survive the ecological challenge of high salt and too little oxygen. Even though salt marsh productivity is very high, species diversity is very low. Salt marsh communities are dominated by a few species of halophytes, plants, that are adapted for growth and reproduction in a saline environment. The height of the species ranges from 100 to 200 cm along the creek banks. Recent evidence suggests that the commonly observed tall and short forms may be genetically distinct, numerous studies have demonstrated that the difference in productivity between forms is a function of environmental variables [12-13].

2.3 Distribution Research

In order to know the distribution of the species in Horikawa river, we mapped the species using the 50m measure and GPS (Garmin) in 9th April, 2019, through the river. When we detect the species, we made the quadrat (1m x 1m) and measured the vegetation cover percentage by photographs. And the reproduction of seeds was counted on 20th Sep. 2019. We set the quadrat (1m x 1m), and harvest all the reproduction stems. After harvest, all stems put into polyester bags with ethanol not to help expansion of the species. The number of seeds at each stems was counted at laboratory.

2.4 Environmental Factor Measurements

For the measurement of environmental factors, we set 130 plots (2m x 2m) in Fig. 2 for the distribution of the species is edge of the river. The water vein is right side. The samplings and measurement were carried out on 130 plots in summer (2nd Aug. to 20th Sep. in 2019). The four environmental parameters, altitude from sea level (*h*), pH (*ph*), loss on ignition (*IL*) and NaCl (*psu*) concentration were measured in each plot. The altitude from sea level was measured using measure pole for leveling. The water pH was measured pH meter (TOA DDK). Loss on ignition was measured by sampling mud (core sampling 5cm diameter 5 cm depth). After sampling the mud was into the incubator at 120°C for 2days in order to loss the water. After pretreatment, the weight was measured and they were burned in the muffle furnace (800°C 4days) to measure loss on ignition.

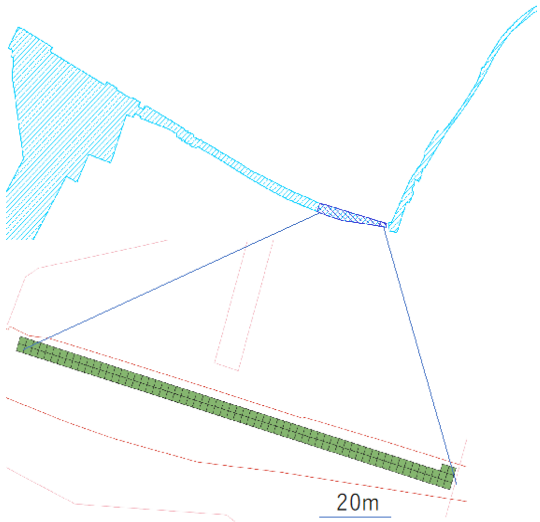

Fig.2 Location of each plots

2.5 Statistical Analysis

We performed analysis using GLM (using quick-R: correspondence analysis program) to elucidate habitation density of the *S. alterniflora* and its relationship to environmental factors. The Environmental parameters used in this study assumes four kinds of measurement data. The population of *S. alterniflora* at each plot was used the distribution research data.

In this study, the response is the population density of *S. alterniflora*. Thus, we supposed that the probability distribution of the response obeyed negative binomial distribution. To explain the distribution of density, our model assumes the main effect term (when a factor acts alone) and an interaction term (when two factors interact). In the case of interaction terms, we performed centration for 2 variables beforehand and incorporated it as an explanatory variable. In total, the model assumes 6 variables of interaction between 2 factors as explanation variables, in addition to the main effect variable (4 variables). As a standard to evaluate the good model, we used by Akaike's information criterion (AIC).

3. RESULTS

3.1 Distribution

Distribution of *S. alterniflora* was shown in Fig. 3. The total area was 499 m^2, 93 populations were detected. The population was not always linked, 430m distant was observed between two next populations.

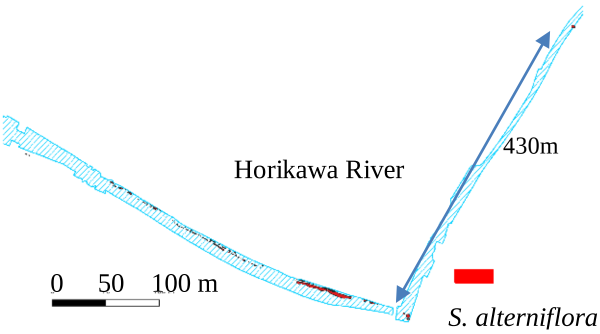

Fig. 3 Distribution of *S. alterniflora* in Horikawa River

The number of seed reproduction at each shoot was shown in Fig. 4. There were 4 times differences about seed production at each shoot. The mean seed production was 19908/m^2.

3.2 Field Census

Figure 5 showed the population density of the species. The unit of the range is vegetation cover area percentage. The census was carried out from 0-100% vegetation cover at 130 plots.

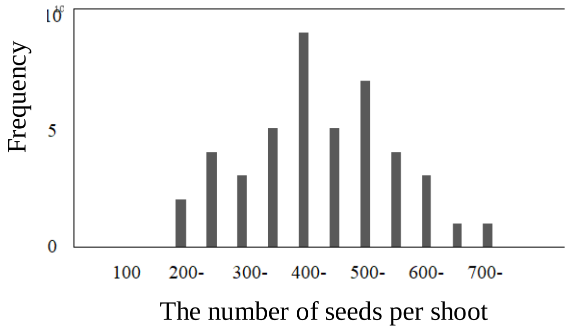

Fig. 4 The histogram of seed production at each shoot

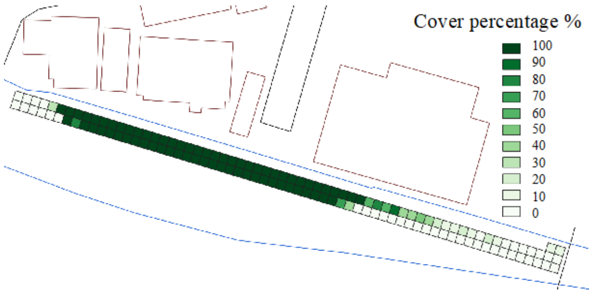

Fig. 5 Population density of *S. alterniflora* at modeling area in Horikawa River

Fig. 6 shows the environmental descriptors of environmental factors in census area. The altitude from sea level is 0 to 102m. The edge of the river is higher because of higher river bed. The pH is ranged from 6.8 to 7.9. The higher level is observed the right side of the Fig. 6-b. The loss on ignition showed distributions at the center of the research areas (in Fig. 6-c). The distribution of NaCl ranges from 0.7% to 1.4%, the NaCl level is lower than sea water.

Fig. 7 showed the relationships between the vegetation percentage of the species and four parameters. Clear relationships between the vegetation cover percentage and four parameters were not observed.

3.3 The Habitation Model

A newly created *S. alterniflora* habitation model of this area found the main relationship effect variable on population density to be the standardization parameter the altitude from sea level, with a value of 4.158. This was the biggest value by the absolute value of all effects calculated. The Wald statistic value was 42.426 indicating significance. Secondary the standardized pH value was also high, 0.925. The Wald statistic value was

16.924. The statistics value of the model was shown in Table 1.

Fig. 8 shows the habitation model from the general linear model. The habitation model was made of parameters shown in Table 1, that is altitude from sea level (*h*), pH (*ph*), the loss of ignition (*IL*) and NaCl concentration (*psu*), the relationships parameters *h:ph*, *h:spu*, *ph:IL*, *ph:psu* and *IL:spu*. Large parts of the calculated habitation model agree with the observed distribution data. Form the data the census and the expectation model, Fig. 9 shows there was a relationship between expected density and the observed density. In 92% of the plots the difference of the vegetation cover percentage is under 20 percentage.

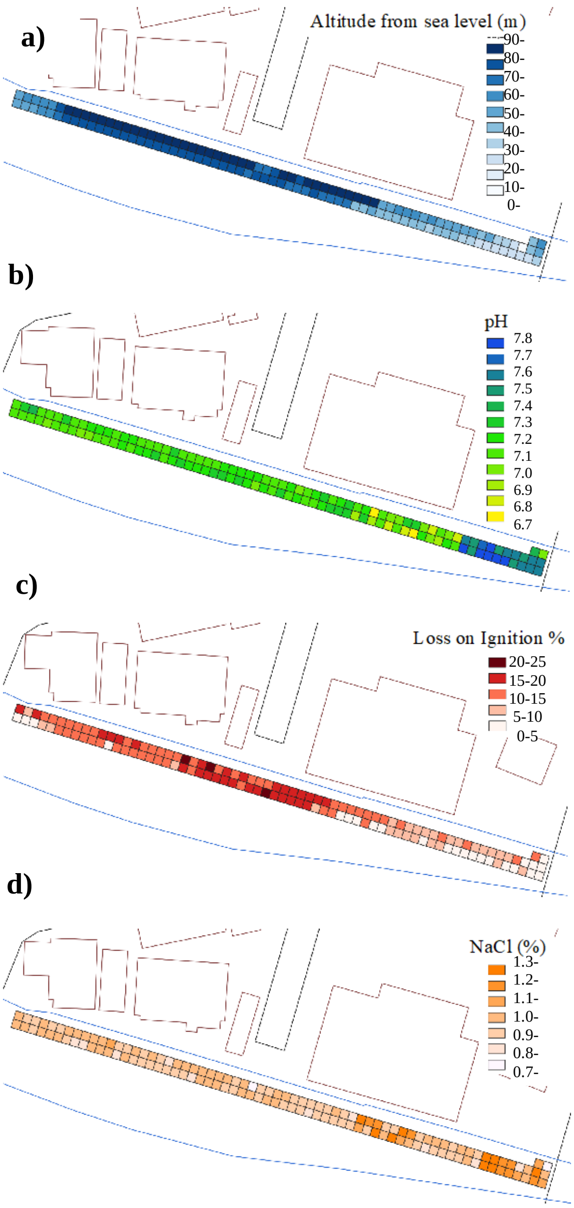

Fig.6 Population density of *S. alterniflora* at modeling area in Horikawa River, a) The altitude from sea level, b) pH, c) The loss of ignition, d) NaCl percentage of water

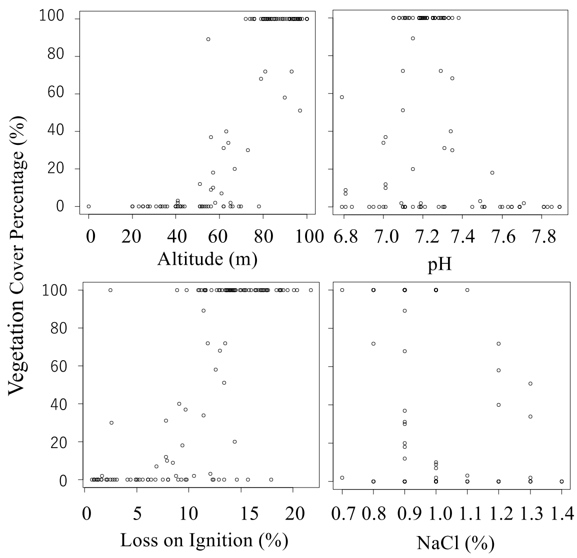

Fig. 7 The relationships between the vegetation cover percentage and four environmental parameters

Table 1 The new model analysis parameters by new general linear model

parameter	β	SE	Wald *z* value	*P* value
α	0.005	0.047	0.038	0.97
h	4.158	0.098	42.426	0.016***
ph	0.925	0.055	16.902	0.016***
IL	-0.446	0.071	-6.307	0.000***
psu	-0.772	0.062	-12.49	0.016***
h:ph	1.007	0.12	9.831	0.016***
h:psu	-0554	0.090	-6.144	0.000***
ph:IL	-0.865	0.088	-9.790	0.016***
ph:psu	0.208	0.051	4.64	0.000***
IL:psu	-0.691	0.085	-8.116	0.000***

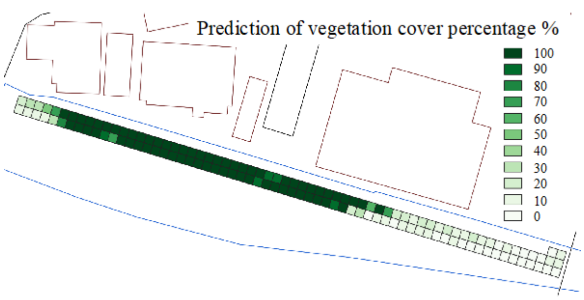

Fig. 8 Suitable habitation model of *S. alterniflora* predicted density. The unit of the range is percentage of vegetation cover

8% of the plots were different from the expectation. The distribution of the plots was far away of the center of the distribution.

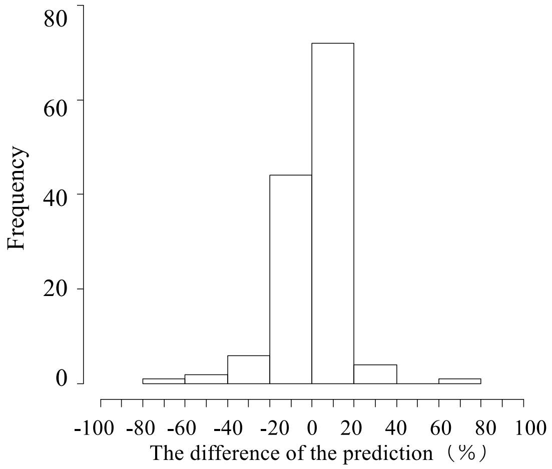

Fig. 9 The histogram is the differences of the population between the predicted value and the observation value

4. DISCUSSIONS

From the data of Horikawa River, the area of *S. alterniflora* was dredged for stinking ooze in 2013. It is expected the invasion of the species is almost 10 years ago. Then the species has been widespread in Aichi Pref. before 2013. The production of the seeds expected 5176 seeds/m^2 by our data, the total seed production of the area would be over 2500000 seeds. Hayasaka (2020) reported the percentage of the seeds is almost 60% then 1300000 seeds dispersed in 2020. The invasive ability is serious problems [14]. In 2016 5 km away from this area, single population was observed in Agui River, near sea shore. The population may be connected the Horikawa River population.

The Agui River population was easily removed because of the short time invasion, it was very lucky occasion. In Toyohashi City the cost of the removal was almost over 30 million yen. It is very important that we find out the population as soon as the invasion occurrence of the species for the cost reduction. Our Japanese land has long seashore line and over 40000 rivers. To find out the invasion rapidly, it is necessary to monitor rivers.

In this study we performed analysis based on four environmental parameters and the 6 relationships between two factors. Some studies used the GLM models and predicted the habitation of each species [15]-[18]. Each model used many environmental factors from 8 to 10. Bur our environmental factors were not so much, and the prediction was suite to the observation distribution. The most impact factor is the altitude from sea levels, secondary pH value. Both the parameters can be easily measured, so we can easily expect the invasion area of the species. The altitude from sea level is 1m and concrete bank is easily invaded by the species.

Though our model explains well the distribution, there are some problems about the environmental factor fluctuation. It was reported that *S. alterniflora* changes a tideland into the grassy plain and it has a big influence on a native species [19][20]. In our study site, five years have already passed after *S. alterniflora* invasion, and environmental condition may change. The sand and mud were gathered at the root of the plants and the height from sea level was changed. After the invasion, it is necessary to investigate the environmental factors at once. Now, the removal of the vegetation of the species and sludge was finished at October in 2019. The environmental factors are changed and the seeds was dispersed in 2018, maybe the invasion will be repeat again. For the improvement of our model, the investigation of the environmental parameters at early invasion stage is needed.

5. CONCLUTION

The following conclusions are drawn from the study.

1) General linear model is effective to more fully understand the habitation area of *S. alterniflora*, invasive plant in sea shore area.
2) However, the species changed the environmental conditions, so more precise investigation needed in order to understand the invasion of the species.
3) From the predictive model, we were able to predict an invasive condition for e environmental factors of the future.

Then our monitoring site should be done below the site,

1) The altitude from the sea level is 0 to 1m and concrete banks should be monitored once a year.
2) Because of the different ecotypes, we should research another area using the general linear model.

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