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ENVIRONMENTAL PARAMETERS CONTROLLING THE HABITAT OF THE BRACKISH WATER CLAM *CORBICULA JAPONICA* IDENTIFIED BY PREDICTIVE MODELLING

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ABSTRACT: The *C. japonica* is an ecologically important species in estuaries and brackish waters, as well as a very important fishery resource. However, the relationship between its habitation conditions and environmental factors remains unclear. We therefore made a habitat prediction model using GLM to define the environment of the *C. japonica* habitat of Lake Shinji, incorporating data acquired from 1982 through 1983 which measured population density, location, silt/clay content, ignition of physical environmental data, pH, dissolved O2 density, chloride ion concentration, and COD of the quality of the water. Our analysis showed that the standardization parameter ignition loss, measuring organic matter and carbonate content in the sediment, was the main effect in the predictive model (estimate -2.22) and had the greatest absolute value. Thus the *C. japonica*'s distribution is dependent on ignition loss, in the predictive model. As for interaction terms modifying distribution, the dissolved O2 and silt/clay content ratio had the largest absolute value at -2.12. In addition, it was revealed that the environmental factors which limit population levels of the *C. japonica* every season are different. These results, while derived from *C. japonica*, also suggest that our GLM model is effective to more fully understand the habitation area of immobile benthoses in general.

Keywords: C. japonica, GLM, Habitat suitability, Environment factor

1. INTRODUCTION

The *Corbicula japonica* is a representative species of estuaries and brackish waters (Figure 1). In Japan, it is widely distributed in brackish water lakes and rivers extending from Hokkaido to Kyushu and has been considered to be an important resource for the brackish water ecosystem as well as playing a major role in the freshwater fisheries.

Brackish water ecosystems are inhabited with a relatively fewer number of species compared to freshwater or saltwater ecosystems [1]. Here, the species must adjust their bodies to the changes in salt concentration by regulating osmotic pressure. On the other hand, the species inhabiting both freshwater and seawater do not have the ability for such adaptation to survive a change in salinity. It is this limitation in physiological function which is thought to constrain the inhabitability of brackish water to adequately adapted species.

Fig. 1 *Corbicula Japonica*

The *C. japonica* has a wide salt tolerance and can survive at all salt concentrations between 0 and 22 ppt [2]. However, although it can survive in both freshwater and seawater, reproduction is severely inhibited. Instead, it requires 5 ppt for reproduction and 1.5 to 22.5 for long-term survival. Because the *C. japonica* can adapt to salt concentration changes, it has become the overwhelmingly dominant species of estuaries and brackish water lakes in Japan. In addition, the *C. japonica* plays an important role in the nitrogen cycle of brackish water area [3]. Therefore it is thought that it is related to maintaining the quality of the water of brackish water area.

Lake Shinji of Shimane Prefecture is a brackish water lake with a large population of *C. japonica*. Present day Lake Shinji is derived from the Old Lake Shinji Gulf, formed when the sea level rose after a global thaw approximately 7,000 years ago. Over time, Old Lake Shinji Gulf and its derivatives have experienced numerous changes in salinity. 5000 years ago, due to an influx of sand and soil supplied by the Hiikawa River, Old Lake Shinji Gulf was separated from the Sea of Japan on the westside but was still connected to the Sea of Japan through the Nakaumi Sea on its east side. As the sea level once again rose 1,200 years ago, seawater returned once more and Lake Shinji became higher in salinity, even more than at the present.

300 years ago, "Tatara iron-making" technology in the mountains near Lake Shinji developed rapidly, causing an increase in sediment runoff which eventually discharged into local streams and the Hiikawa River. As a result of this sediment discharged into Lake Shinji, the bottom of the lake on the east side rose, thus blocking its outflow to the Nakaumi Sea, transforming Lake Shinji into a freshwater lake. Lake Shinji remained a freshwater lake for hundreds of years until the Ohashi River was dredged, starting in 1924 and continuously thereafter. At this point, seawater flowing into Lake Shinji increased and it became the current brackish water lake.

As the Lake Shinji has had good salinity conditions for *C. japonica* in particular, and they were allowed to thrive more than other species, an industry-tailored toward harvesting them at Lake Shinji was developed. The catch of the *C. japonica* in Japan was approximately 60,000 tons in the 1970s, although it has drastically decreased since then, with a catch of approximately 7,800 tons in 2012. Lake Shinji in Shimane Prefecture is the main production center of *C. japonica*, with the largest fish harvests in the country. Approximately 20,000 tons were harvested in1973, but likewise decreased continually thereafter, and the yield of the *C. japonica* in Lake Shinji became approximately 3,400 tons in 2014. Initially, fishermen thought the lower catch was due to a decrease in the natural population of *C. japonica* and set catch limits, however, the decrease in catch amounts did not stop.

Several factors may have influenced the drop in the *C. japonica* population. Rapid economic growth from the 1960s through the 1970s led to increased water pollution in Lake Shinji. Construction of the Ohara dam on the Hiikawa River was completed in the 1980s. Furthermore, the construction of Hiikawa River and the Hiikawa flood control channel to provide linkage with the Kando River began in the 1990s. Thus the environment of the watershed surrounding Lake Shinji has greatly changed artificially. The ecosystem may also be greatly influenced by conventional maintenance such as river repair [4]. It is, therefore, necessary to examine the relationship between the river environment and the change of the quantity/quality of the natural resources used by *C. japonica*.

Importantly, the ecology of the *C. japonica* has many factors which have not been elucidated, and it has been difficult to identify the factors that have led to the reduction in its population. We, therefore, made a habitat prediction model using GLM (generalized linear model) to further define the environment of the *C. japonica* habitat. In a protection plan of the animal, analysis using GLM is carried out for relation about habitation density and environmental factors [5].

In this analysis, we considered the habitation restriction factors of the *C. japonica* in Lake Shinji.

2. MATERIAL AND METHODS

2.1 Study site

The place of the investigation was Lake Shinji, located in northeast Shimane Prefecture, Japan (Figure 2). Lake Shinji is approximately 17 km east-to-west and 6 km north-to-south, with a circumference of 47 km and an area of 79.25 km^2. Its mean water depth is 4.5 m, and a maximum depth of the water is 6.4m. Lake Shinji is the seventh largest lake in Japan by area. The average temperature is 14.4^{o}C and receives 1800 mm of precipitation per year. Especially, it is much precipitation in summer and winter. The inflow rivers to Lake Shinji flows in from the north, the west, and the south, with the Hiikawa River being the greatest. Lake Shinji outflows to the Sea of Japan through the Nakaumi Sea and subsequently the Sakaisuido Channel via the Ohashikawa River, from where mingling seawater and freshwater produce the brackish lake water.

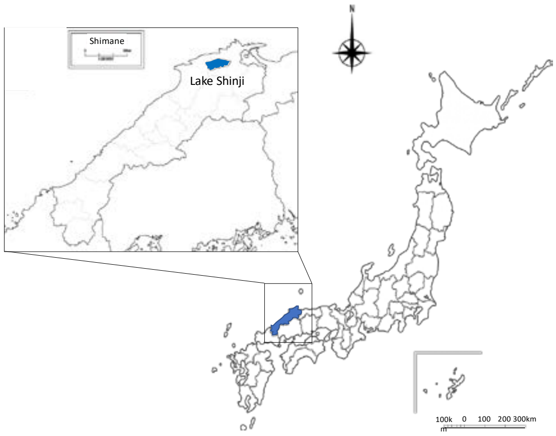

Fig. 2 Map of sampling locality

2.2 Sampling Methods

The samplings were carried out on 248 plots (Figure 3) in summer (18th Jul. to 11th Aug in 1982), on 60 plots in spring (25th to 30th Apr. in 1983) and in autumn (25th to 30th Oct. in 1983). The eight environmental parameters, water depth, water temperature, pH, dissolved oxygen density, chloride ion concentration, chemical oxygen demand (COD), loss on ignition, clay sediment granulometry (<75 μm, 75 μm -2 mm, >2 mm), and silt content, were measured in each season. The sampling method of bottom water was done by

Kitahara-type B sampler within 10cm from the bottom. The sampling of bottom mud was done by Ekman-Birge grab. The water pH was measured pH meter (TOYO TD21R), Dissolved oxygen density was measured sodium azide variant method, chloride ion concentration was measured Mole method, chemical oxygen demand was Alkaline permanganate acid method. Dried cores were burned in the muffle furnace (800ºC 4days) to measure loss on ignition. Clay/silt ratio was measured 0.075mm mesh sieve.

To count the number of *C. japoinica*, we used Smith McIntire grab (0.05 square meters) 1 to 3 times at each plot. The sampling mud was washed by a 0.05 mm mesh sieve and remained matter was fixed with 10% formalin. Over 4 mm size of *C. japonica* were counted in each plot.

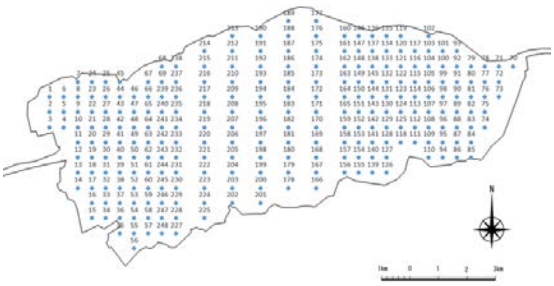

Fig. 3 Lake Shinji and the dots indicate the sampling spots.

2.3 Statistical Analysis

We performed analysis using GLM (using quick-R: correspondence analysis program) to elucidate habitation density of the *C. japonica* and its relationship to environmental factors. The environmental parameters used in this study assumes eight kinds of measurement data. The population of *C. japonica* at each plot was converted to individual counts per square meter.

In this study, the response is the population density of the *C. japonica*. Thus, we supposed that the probability distribution of the response obeyed negative binomial distribution. In the case of zero data (plots where 0 individuals were recovered), these were excluded from the response model.

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 28 variables of interaction between 2 factors as explanation variables, in addition to the main effect variable (8 variables).

As a standard to evaluate the good model, we used by Akaike information criterion (AIC).

3. RESULTS

3.1 Field Census

The population density of the *C. japonica* varied according to the season. The result of each season is compiled in Table1. The summer season had the highest density as compared to spring and fall (Table 1, Figure 4). About half of the surveyed sites, the population density of *C. japonica* was 0 at each season. In all seasons, the habitation of *C. japonica* was not confirmed in the center of the lake.

Table 1 The density of *C. japonica* (number/m^2) in each plot. A number of plots was indicated in parenthesis.

Season(No.)	Mean±SD	Max	Min (No.)
Summer(248)	329±1,134	5,030	0(125)
Summer(60)	463±857	3,890	0(26)
Spring(60)	229±410	1,620	0(26)
Fall(60)	256±407	2,140	0(27)

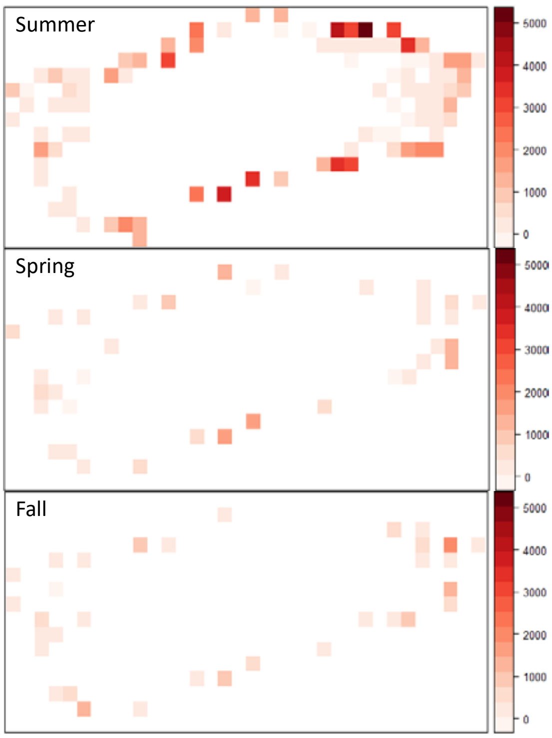

Fig. 4 The population density of the *C. japonica*. The unit of the range is number/m^2.

Figure 5 and 6 shows the environmental descriptors of water and bottom sediment in summer. The water depth of Lake Shinji was 0-6 m, and it is deepest at the center of the lake. The maximum water depth was 5.6 m. Seasonal change in water depth was not observed.

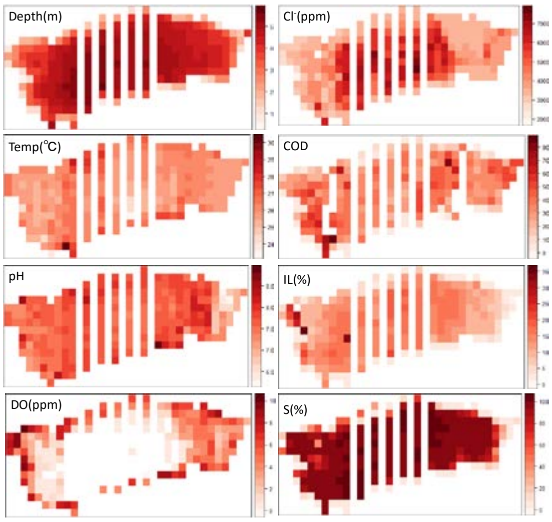

Fig. 5 Environmental parameters as indicated of each plot in the summer census of Lake Shinji.

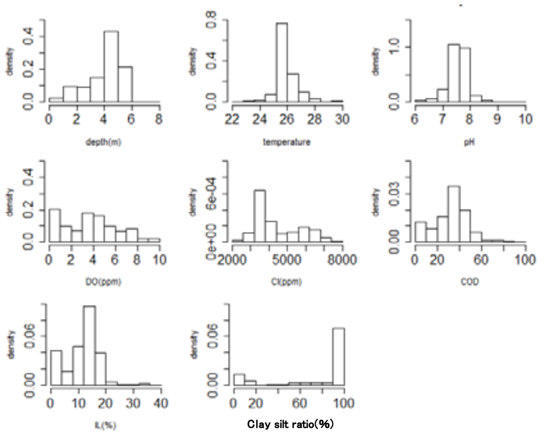

Fig. 6 Probability distribution of environmental factors in the summer.

The water temperature (Temp) was uniform in the summer. But a part of the north lake shore and south lakeshore exceeded 28 ^{o}C. The summer term was 8^{o}C warmer than the other seasons. pH measurements ranged from7-8 within the whole lake. Dissolved oxygen (DO) was less than 3 ppm at the center of the lake in the summer. In general, it is said the survival of aquatic organisms becomes difficult when the dissolved oxygen DO is under 3 ppm. In other seasons, the same values as described were seen except for dissolved oxygen, which was lower in summer. Chloride ion density (Cl^-) was also higher in the center of the lake than other plots in summer.

The values of COD (chemical oxygen demand) and ignition loss (IL) showed distributions at the center of the lake at levels detrimental for habitation. The distribution of the clay silt ratio (S) showed a value of 80-90% in the center of the lake, 4 times higher than other areas throughout the season.

3.2 *C. Japonica* Habitation Model

A newly created *C. japonica* habitation model of the summer season found the main relationship effect variable on population density to be the standardization parameter ignition loss (IL), with a value of -2.22. This was the biggest value by the absolute value of all effects calculated. The Wald statistic value was -5.644 indicating significance. As for interactions, the value of the standardization parameter dissolved oxygen (DO) and the clay silt ratio (S) was calculated to be -2.22, which was the largest absolute value of all interaction terms. Furthermore, the clay silt ratio (S) influences many parameters, and it is thought that it is an important parameter.

In the model of the spring season, statistical significance was confirmed in all parameters. As for interactions, the value of the standardization parameter of COD and the clay silt ratio (S) by was calculated to be 25.06, which is the largest absolute value. Secondly, the parameter of COD and the clay silt ratio (S) was 23.98.

In the fall, significance was confirmed in all parameters. As for interactions, the value of the standardization parameter water depth (D) and COD was calculated to be -166.49 and is the biggest by absolute value. Secondly, ignition loss (IL) and the clay silt ratio (S) was -111.79.

3.3 Suitable Habitation Model

Figure 7 shows the habitation model for each season from the GLM. The habitation model was made of water depth, water temperature, pH, DO, chloride ion concentration, chemical oxygen demand, loss on ignition, clay sediment granulometry, and silt content.

Large parts of the calculated habitation model agree with the observed distribution data.

From the data of the census and the expectation model, Figure 8 shows there was a relationship between expected density and the observed density. The model of the fall season is most consistent with observed data.

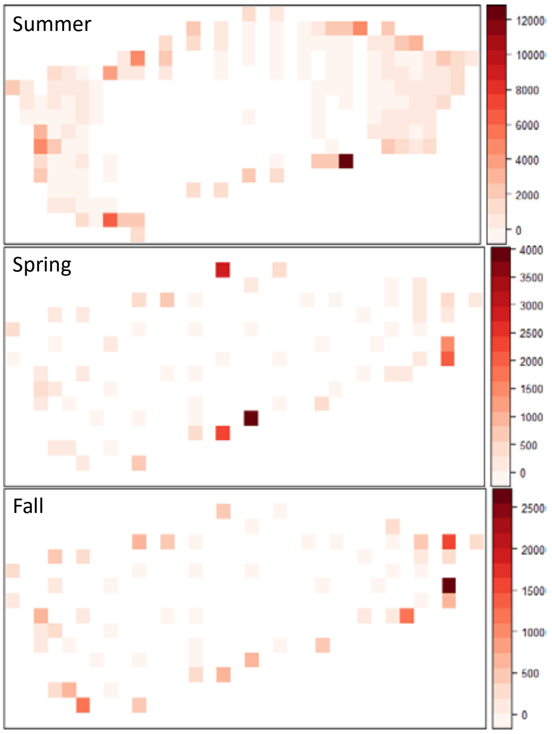

Fig. 7 Suitable habitation model of *C. japonica* predicted density. The unit of the range is number/m^2.

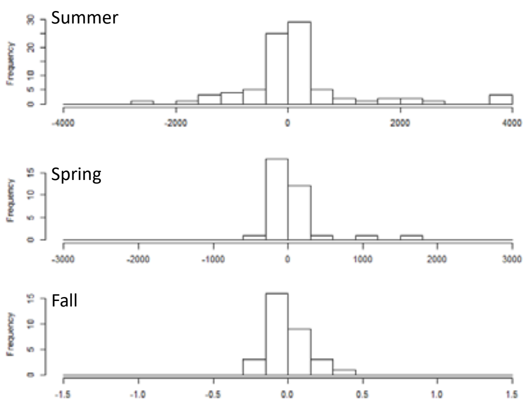

Fig. 8 The histogram is the differences of the population between the predicted value and the observation value of each season.

4. DISCUSSION

In this study, we performed analysis based on a supposition that an error structure of response y obeyed negative binomial distribution. However, the response had many 0 data, and a state of the overdispersion was confirmed. When a response has a significant amount of 0 data, statistics processing becomes difficult. This is because bias is given to the distribution model [6], [7]. It has been suggested that GLM is not a good model for analysis of distribution as they had used all data points. In this paper, we used GLM analysis excluding only the 0 data, which greatly reduced the numbers of samples analyzed. However, our model was able to be predictive due to the high number of samples. The precision of the predictive model using GLM was low when there were many 0 data in the study of Silveira and others [8]. After performing analysis with the data from three seasons in this model, it was shown that environmental factors affecting the habitation of the *C. japonica* by season were different. In other words, it was revealed that it is applicable to GLM by considering the data between seasons when there were many 0 data. Specifically, as the benthos, in particular, has low mobility and is easy to receive environmental action [9], it is thought that the construction of the habitation model using GLM is effective. In the analysis of GLM for animals having high mobility, the importance of the seasonal variation is suggested [10].

Lake Shinji is the main production district of the *C. japonica* and harvesting of the *C. japonica* is carried out through the year. The fisherman of Lake Shinji has been limiting fish catches and the fishery size for fisheries resource conservation. Only large individuals are removed from Lake Shinji by fishing. On the other hand, small individuals are not affected by the fishery. Thus, in the area where the fishery is prosperous, it is important to investigate the habitation conditions of the small individuals and their environment. Despite this, it is thought that there is a large natural decrease in the population prior to maturation. After having shifted to bottom-dwelling after the floating larva period, increased damage to the population of the next generation of natural resources will occur if there are few individuals which are able to mature. Therefore, the construction of a habitation model of the *C. japonica* that focuses on the habitat environment of the small individual is in demand.

Recently maintenance of a river and the wetlands by flood measures has been an important issue. At the same time, such maintenance is demanded from the consideration to the environment. Some models for the purpose of the environmental grasp are thought about [11]. While such efforts are necessary for the maintenance of the environment, there are many uncertain points. As a result of this analysis, we have shown it is possible to apply a model by GLM about *C. japonica* and various environmental factors. However, it is necessary for the survey data to be considered seasonally. By the assessment of the maintenance of rivers and wetlands, it is thought that a habitat environment prediction of the *C. japonica* is possible from the result of the four seasons investigation.

5. CONCLUSIONS

The following conclusions are drawn from the study.

1) The GLM model is effective to more fully understand the habitation area of *C. japonica*, immobile benthoses in general.
2) However, it is necessary to take the data every season because there is a seasonal change in the habitation situation.
3) From a predictive model, we were able to predict a condition necessary for the environmental maintenance of the future lake.

6. ACKNOWLEDGMENTS

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