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Spatial and Temporal Distribution Pattern of *Oncomelania hupensis* Caused by Multiple Environmental Factors Using Ecological Niche Models

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Objective: This study aimed to predict the spatial and temporal distribution pattern of *Oncomelania hupensis* (*O. hupensis*) on a fine scale based on ecological niche models, so as to provide insights into *O. hupensis* surveillance.

Methods: Geographic distribution and environmental variables of *O. hupensis* in Suzhou City were collected from 2016 to 2020. Five machine learning algorithms were used, including eXtreme gradient boosting (XGB), support vector machine (SVM), random forest (RF), generalized boosted (GBM), and C5.0 algorithms, to predict the distribution of *O. hupensis* and investigate the relative contribution of each environmental variable. The accuracy of the five ecological niche models was evaluated using the area under the receiver operating characteristic (ROC) curve (AUC) with ten-fold cross-validation.

Results: Five models predicted that the potential distribution of *O. hupensis* was in southwestern areas of Wuzhong, Wujiang, Taichang, and Xiangcheng counties. The AUC of RF, XGB, GBM, SVM, and C5.0 algorithms were 0.8233, 0.8051, 0.7938, 0.7897, and 0.7282, respectively. Comparing the predictive results and the truth of *O. hupensis* distribution in 2021, XGB and GBM models were shown to be more effective. The six greatest contributors to predicting potential *O. hupensis* distribution included silt content (13.13%), clay content (10.21%), population density (8.16%), annual accumulated temperatures of ≥0°C (8.12%), night-time lights (7.67%), and average annual precipitation (7.23%).

Conclusions: Environmental factors play a key role in the spatial and temporal distribution pattern of *O. hupensis*. The XGB and GBM machine learning algorithms are effective and highly accurate for fine-scale prediction of potential *O. hupensis* distribution, which provides insights into the surveillance of *O. hupensis*.

Keywords: spatial and temporal distribution, ecological niche model, *Oncomelania hupensis*, Suzhou City, environmental factors

INTRODUCTION

Schistosomiasis japonica, a zoonotic parasitic disease caused by infection of the *Schistosoma* species, seriously endangers human health and socioeconomic development, which is one of the major global public health concerns (Song et al., 2016). China once bore the world's highest burden of Schistosomiasis japonica (Zhou et al., 2021). Following concerted efforts for more than 70 years, remarkable achievements have been made in the national schistosomiasis control program of China (Cao et al., 2020; Yang et al., 2020). There were 74.89% of the total 450 schistosomiasis-endemic counties which achieved schistosomiasis elimination, 21.78% achieved transmission interruption, and 3.33% achieved transmission control by 2020 (Qian et al., 2019; Zhang et al., 2021). The shift moving toward schistosomiasis elimination suggests that the schistosomiasis control emphasis shifting from controlling the source of *S. japonicum* infections to risk monitoring, and the surveillance of the intermediate host *O. hupensis* distribution is the most important part for the monitoring of the schistosomiasis control risk (Gong et al., 2017).

Suzhou City was once highly prevalent for schistosomiasis in China with accumulative *O. hupensis* habitats of 414.33 km^2. Following the long-term implementation of integrated interventions targeting schistosomiasis, including *O. hupensis* survey, *O. hupensis* control with chemical treatment and environmental improvements, the transmission of schistosomiasis has been effectively interrupted in Suzhou City, with more than 95% reduction in the area of *O. hupensis* habitats (Zhang, 2018; Li et al., 2019). Ecological environments play a key role in the distribution of *O. hupensis* snails, so there are still *O. hupensis* habitats found in local areas of the city, since the ecological environments have not completely changed. During the period from 2011 to 2020, a total of 0.683 km^2 of *O. hupensis* habitats have been identified in Suzhou City, suggesting the long-term potential schistosomiasis transmission risk. *O. hupensis* survey is an important part of schistosomiasis control. The currently used massive sampling survey or census is time-consuming and high in cost, which is difficult for timely and accurate identification of the schistosomiasis transmission risk. Therefore, a rapid, accurate, and low-cost approach is urgently needed for the *O. hupensis* survey during the early stage of *O. hupensis* population spread, which may provide a valuable basis for *O. hupensis* control.

The ecological niche model, which combines environmental variables with known biological distribution, is effective in quantitatively describing the environmental factors associated with biological distribution and recognizing the environmental similarity with known distribution areas in the study regions through modeling based on machine learning algorithms, thus speculating the potential species distribution (Samy et al., 2018; Hu et al., 2020b). As an important tool in ecology and biogeography (Wang and Qiao, 2020), ecological niche models show a high ability for prediction of the geographical distribution of species, and have been widely used to map the temporospatial distribution of species (Mulieri and Patitucci, 2019; Wang et al., 2020; Gong Y. et al., 2021; Liu C. Y. et al., 2021; Ta et al., 2021; Yang et al., 2021), forecast the invasion of alien species (Wang et al., 2018), evaluate the effect of climate changes on species distribution (Liu et al., 2020), and identify the disease

TABLE 1 | Variables included for using the five ecological niche models for prediction of potential *Oncomelania hupensis* distribution in Suzhou City from 2016 to 2020.

Classification of Variables	Variable	Mean	Standard deviation	Spatial resolution	Source
Geographical and environmental factors	Altitude (ALT)	9.73	21.35	1 km*1 km	WorldPop
	Distance from watercourse (DST)	0.44	0.57	1 km*1 km	WorldPop
	Gradient	1.46	3.11	1 km*1 km	WorldPop
Climatic factors	Annual accumulated temperature of ≥0 °C (AAT0)	56,652.64	654.36	500 m*500 m	Resdc
	Annual accumulated temperature ≥10 °C (AAT10)	50,301.06	452.27	500 m*500 m	Resdc
	Aridity (AR)	905.54	25.22	500 m*500 m	Resdc
	Moisture index (MI)	3293.14	346.23	500 m*500 m	Resdc
	Average annual precipitation (Pa)	11,313.18	389.26	500 m*500 m	Resdc
	Average annual temperature (Ta)	155.1	1.83	500 m*500 m	Resdc
Socioeconomic factors	Gross domestic product (GDP)	16,202.98	10,741.43	1 km*1 km	Resdc
	Night-time lights (NTL)	14.65	13.35	1 km*1 km	Resdc
	Population density (PD)	2316.06	6135.3	1 km*1 km	Resdc
Soil index	Clay content	28.66	1.96	1 km*1 km	Resdc
	Sand content	33.11	3.28	1 km*1 km	Resdc
	Silt content	38.22	1.84	1 km*1 km	Resdc
Vegetation index	Normalized difference vegetation index for the 1st quarter (NDVI01)	0.43	0.14	1 km*1 km	Resdc
	Normalized difference vegetation index for the 2nd quarter (NDVI02)	0.53	0.15	1 km*1 km	Resdc
	Normalized difference vegetation index for the 3rd quarter (NDVI03)	0.47	0.14	1 km*1 km	Resdc
	Normalized difference vegetation index for the 4th quarter (NDVI04)	0.26	0.12	1 km*1 km	Resdc

transmission risk (Alkishe et al., 2021). Liao's study based on 16 ecological niche models found that climate changes were predicted to pose a great impact on the distribution of *O. hupensis* snails, resulting in north expansion and south shrinkage of the ecologically suitable *O. hupensis* habitats (Liao, 2011). Hu's study based on 10 ecological niche models suggested that the areas at a high risk of schistosomiasis transmission were predicted to be mainly distributed in northern Heqing County, eastern Eryuan County, central Dali City, northeastern Weishan County, and northern Midu County (Hu et al., 2020a). This study aimed to predict the spatial and temporal distribution pattern of *O. hupensis* in Suzhou City using ecological niche models based on multiple environmental factors, so as to provide a basis for *O. hupensis* survey and control and assessment of the potential schistosomiasis transmission risk.

MATERIALS AND METHODS

Study Area

Suzhou City is located in the lower reaches of the Yangtze River, in which there are plenty of rivers and lakes, and the area of rivers, lakes, and marshlands consists of 36.6% of total land areas in the city. In addition, Suzhou City has a moderate climate, abundant rainfall, fertile soil, and widespread vegetation, which is very suitable for *O. hupensis* breeding (Wang and Qiao, 2020).

Data Collection

O. hupensis distribution data, which were retrieved from *O. hupensis* habitat report cards in Suzhou City from 2016 to 2020, were provided by the Suzhou Center for Disease Control and Prevention (SZCDC), including the longitude, latitude, and area of *O. hupensis* habitats. There were 32 *O. hupensis* habitats found from 2016 to 2020, and all data were managed using the software Microsoft Excel 2013.

The datasets of factors affecting *O. hupensis* distribution in Suzhou City were collected, including five categories of geographical and environmental factors, climatic factors, socioeconomic factors, soil index, and vegetation index (**Table 1**), and 19 variables: altitude (ALT), distance from watercourse (DST), gradient, annual accumulated temperature of ≥0°C (AAT0), annual accumulated temperature ≥10°C (AAT10), aridity (AR), moisture index (MI), average annual precipitation (Pa), average annual temperature (Ta), gross domestic product (GDP), night-time lights (NTL), population density (PD), clay content, sand content, silt content, normalized difference vegetation index for the 1st quarter (NDVI01), normalized difference vegetation index for the 2nd quarter (NDVI02), normalized difference vegetation index for the 3rd quarter (NDVI03), and normalized difference vegetation index for the 4th quarter (NDVI04). Climatic data, socioeconomic status, soil index, and vegetation index were captured from the Resource and Environment Science and Data Center, Chinese Academy of Sciences (CAS) (https://www.resdc.cn/), and the geographical and environmental data were retrieved from the WorldPop Data Portal (https://www.worldpop.org). The administrative division map of Suzhou City was downloaded from the National Geomatics Center of China (http://www.ngcc.cn/ngcc/). All raster data were re-sampled to the resolution of 500 m × 500 m using the software ArcGIS version 10.2 and cut to match the map of Suzhou City for the subsequent analysis.

Ecological Niche Modeling

Ecological niche models were used based on five machine learning algorithms using the Classification and Regression Training (CARET) package in the R version 3.6.1, including eXtreme gradient boosting (XGB), support vector machine (SVM), random forest (RF), generalized boosted (GBM), and C5.0 algorithms. *O. hupensis* habitats detected in Suzhou City from 2016 to 2020 and all background data were included in ecological niche models, and 80% were randomly selected as a training dataset, with 20% as a test dataset. The probability of *O. hupensis* distribution in each grid was estimated. The settings with a 0–30% probability of *O. hupensis* distribution were defined as non-suitable habitats, 30.1%–50% as low-probability suitable habitats, 50.1%–70% as moderate-probability suitable habitats, and 70.1%–100% as high-probability suitable habitats. The relative contribution of each variable to the prediction of potential *O. hupensis* distribution was estimated using the CARET package.

Assessment of the Predictive Accuracy of Ecological Niche Models

The accuracy of the five ecological niche models for the prediction of potential *O. hupensis* distribution was evaluated using the area under the receiver operating characteristic (ROC) curve (AUC) with ten-fold cross-validation. The mean values of AUC were calculated with a 95% confidence interval. The AUC mean value, ranging from 0 to 1, indicates the predictive accuracy of the ecological niche models, and an AUC value approaching 1 indicates higher accuracy (Hu, 2020).

Field Validation

A cross-sectional survey was conducted by means of systematic sampling and environmental sampling according to the *Technical Guidelines for O. hupensis in China* in Suzhou City in 2021, to investigate the longitude and latitude of *O. hupensis* habitats and *O. hupensis* density. The *O. hupensis* survey results were recorded in *O. hupensis* habitat report cards, and managed using the software Microsoft Excel 2013. The degree of concordance between the prediction results by ecological niche models and actual *O. hupensis* distribution was examined.

RESULTS

Current Distribution of *O. hupensis* Habitats

A total of 0.659 km^2 of *O. hupensis* habitats were found in Suzhou City during the period from 2016 to 2020, which peaked in 2018 (0.499 km^2). During the 5-year study period, the highest mean density of *O. hupensis* was seen in 2017 (0.068 *O. hupensis* snails/0.1 m^2), followed by 2016 (0.044 *O. hupensis* snails/0.1 m^2), and *O. hupensis* habitats were predominantly

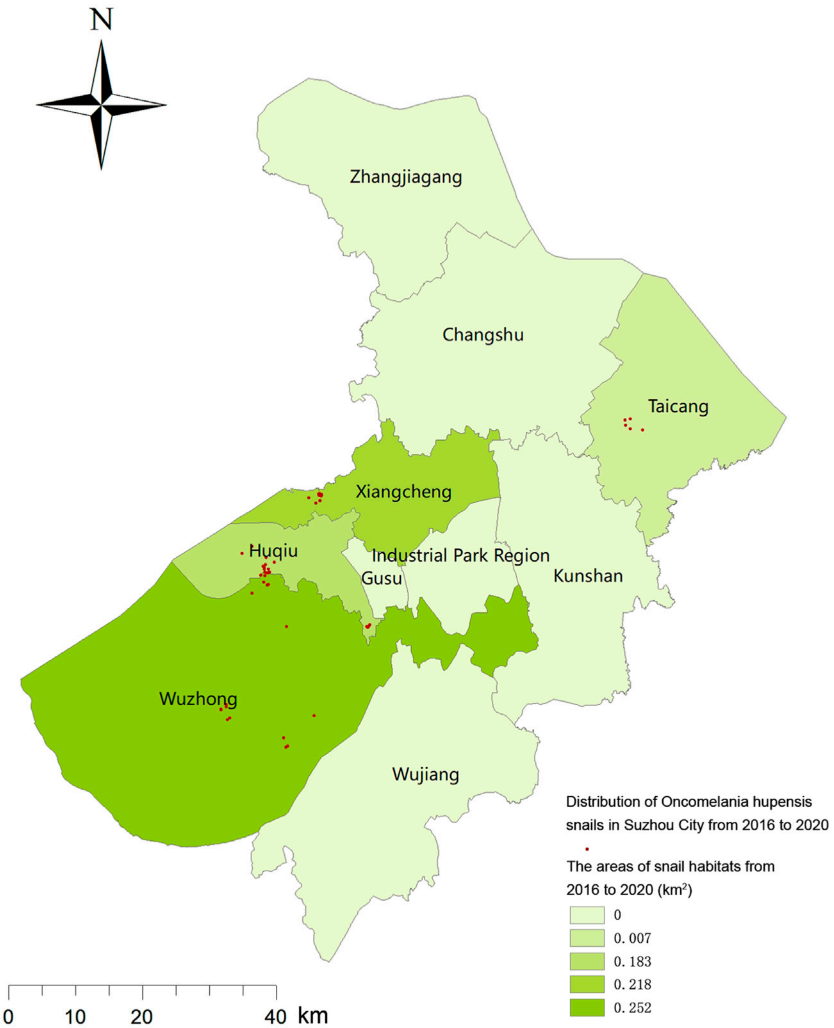

FIGURE 1 | Distribution of *Oncomelania hupensis* in Suzhou City from 2016 to 2020.

identified in three townships of Huqiu, four townships of Wuzhong, two townships of Xiangcheng, and one township of Taicang (**Figure 1**).

During the 5-year period from 2016 to 2020, the largest *O. hupensis* habitats were identified in Wuzhong (0.252 km^2), followed by in Xiangcheng (0.218 km^2), Huqiu (0.183 km^2), and Taichang (0.007 km^2) (**Table 2**). *O. hupensis* habitats were found in Guangfu and Jinting townships of Wuzhong in each of the 5 years, and *O. hupensis* habitats were found in the Zhenhu Township of Huqiu and Dongshan Township of Wuzhong in 4 years, while *O. hupensis* habitats were detected in the Dongzhu Township of Huqiu during the past 3 years.

Ecological Niche Modeling and Prediction

Fine-scale ecological niche models were used based on five machine learning algorithms to predict the probability of *O. hupensis* distribution in Suzhou City. Suitable habitats of *O. hupensis* were predicted in Wuzhong, Wujiang, Taicang, and southwestern Xiangcheng by all five ecological niche models, and high-probability suitable habitats were found in central Wuzhong (Dongshan and Jinting townships) (**Figure 2**). The SVM and C5.0 algorithms predicted high-probability suitable habitats of *O. hupensis* in northern Wuzhong (Guangfu Township) and southwestern Xiangcheng (Wangting Township), and GBM and XGB models predicted high-probability suitable habitats in northern Wuzhong (Guangfu, Xukou, Xiangshan, and Hengjing townships) and central Huqiu (Jinghu and Dongzhu townships). Overall, the suitable habitats of *O. hupensis* predicted by GBM and C5.0 algorithms were predominantly located in the southern half of Suzhou City, and across the city by XGB, SVM, and RF models.

The C5.0 algorithm predicted the largest suitable habitats of *O. hupensis* (8.71% of total areas in Suzhou City), followed by RF (5.09%), GBM (5.06%), XGB (3.31%), and SVM models (2.2%), and the XGB model predicted the largest high-probability suitable habitats (0.7% of total areas in Suzhou City), followed

TABLE 2 | Distribution of *Oncomelania hupensis* in Suzhou City from 2016 to 2020.

Year	County	Township (streets)	Snail habitat (m^2)	Snail density (snail/ 0.11 m2)	*Schistosoma japonicum* infection in snails (%)	Snail habitats in the city (m^2)	Snail density in the city (snail/ 0.11 m^2)
2020	Huqiu	Dongzhu	11,650	0.005	0	77,355	0.020
	Huqiu	Jinghu	510	0.002	0		
	Wuzhong	Guangfu	7300	0.040	0		
	Wuzhong	Dongshan	5500	0.044	0		
	Wuzhong	Jinting	500	0.011	0		
	Xiangcheng	Wangting	51,895	0.246	0		
2019	Huqiu	Dongzhu	18,700	0.087	0	56,206	0.016
	Huqiu	Zhenhu	906	0.003	0		
	Wuzhong	Guangfu	21,000	0.022	0		
	Wuzhong	Dongshan	13,000	0.035	0		
	Wuzhong	Jinting	100	0.040	0		
	Wuzhong	Xiangshan	2500	0.190	0		
2018	Huqiu	Hengtang	680	0.046	0	498,590	0.102
	Huqiu	Zhenhu	60	0.001	0		
	Huqiu	Dongzhu	148,550	0.278	0		
	Wuzhong	Jinting	1800	0.035	0		
	Wuzhong	Dongshan	600	0.009	0		
	Wuzhong	Guangfu	182,200	0.328	0		
	Xiangcheng	Huangdai	164,700	0.037	0		
2017	Huqiu	Hengtang	420	0.500	0	6250	0.068
	Wuzhong	Jinting	1200	0.049	0		
	Wuzhong	Guangfu	600	0.011	0		
	Xiangcheng	Huangdai	1000	0.095	0		
	Taicang	Shanxi	3030	0.375	0		
2016	Huqiu	Zhenhu	1120	0.011	0	20,620	0.044
	Wuzhong	Dongshan	2000	0.050	0		
	Wuzhong	Guangfu	13,000	0.050	0		
	Wuzhong	Jinting	500	0.050	0		
	Taicang	Shanxi	4000	0.147	0		
Total						659,021	0.063

by GBM (0.69%), C5.0 (0.26%), SVM (0.12%), and RF models (0.11%) (**Table 3**).

Accuracy of Ecological Niche Models for Prediction of Potential *O. hupensis* Distribution

According to the ROC curve (**Figure 3**), the performance of prediction accuracy of these five models all showed a high accuracy (the AUC mean values > 0.7). The AUC mean values of RF, XGB, GBM, SVM, and C5.0 algorithms were 0.8233, 0.8051, 0.7938, 0.7897, and 0.7282, respectively. For the prediction performance of *O. hupensis* potential distribution in Suzhou City, the RF, XGB, and GBM indicated a higher accuracy among these five ecological niche models for the prediction of potential *O. hupensis* distribution.

Among the 19 variables, the six greatest contributors to the prediction of *O. hupensis* distribution included the silt content in soil, clay content, population density, annual accumulated temperatures of ≥0°C, night-time lights, and average annual precipitation (**Figure 4**).

The results from the response-curve analysis showed that the silt content of more than 40%, clay content of less than 28%, population density between 2000 and 3000 persons/km^2, annual accumulated temperatures of ≥0°C between 55,500 and 56,500°C days, night-time lights of more than 10 nW/cm^2/sr, and average annual precipitation between 11,250 and 12,000 mm^3 were the most suitable habitats for *O. hupensis* breeding (**Figure 5**).

O. hupensis survey was performed in current *O. hupensis* habitats and potential *O. hupensis* habitats predicted by ecological niche models in Suzhou City in 2021, and covered 83 townships (streets) and 1021 villages (communities) (**Table 4**). The *O. hupensis* survey covered an area of 14.825 km^2, including 1.973, 1.856, 1.734, 0.171, 1.402, 0.582, 3.210, 0.050, 2.043, and 1.804 km^2 in Huqiu, Wuzhong, Xiangcheng, Gusu, Wujiang, Industrial Park Region, Changshu, Zhangjiagang, Kunshan, and Taicang, respectively. A total of five *O. hupensis* habitats were found, which were located in Guangfu, Jinting, and Xiangshan townships of Wuzhong and Dongzhu and Zhenhu townships of Huqiu (**Figure 2**).

The forecast result of the C5.0 algorithm covered all these five habitats; however, only one habitat was located in the predicted high-probability suitable habitats, and the other four habitats were all located in predicted low- and moderate-probability suitable habitats. The predicted result of the XGB model covered four habitats, which were all located in the predicted high-probability suitable habitats. Three habitats were located in the predicted high-probability suitable habitats of the GBM

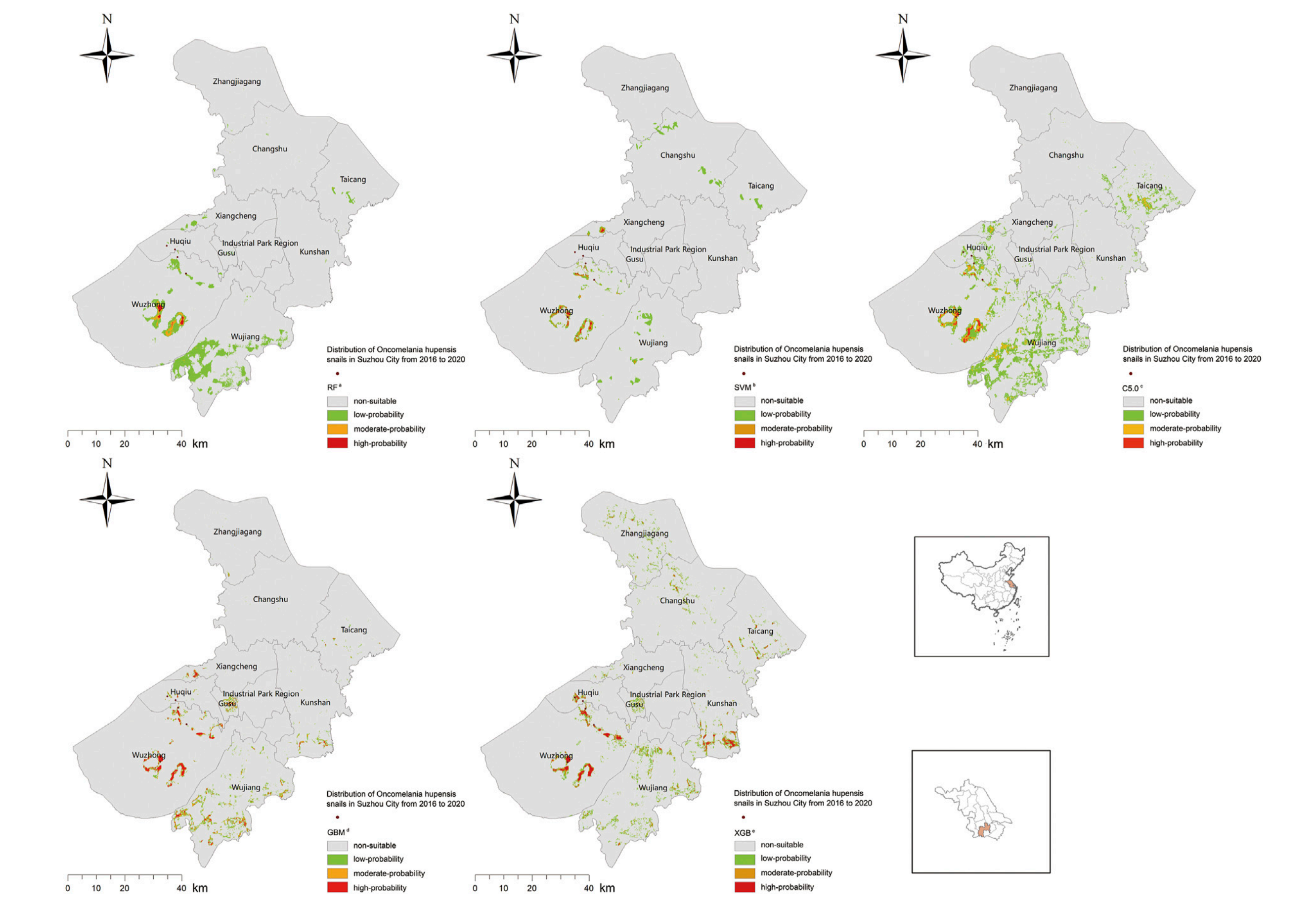

FIGURE 2 | Prediction of suitable habitats of *Oncomelania hupensis* using five ecological niche models.

TABLE 3 | Proportion of the predicted by low-, moderate-, and high-probability suitable habitats by five algorithms in total suitable habitats in Suzhou City (%).

Algorithm	Low-probability suitable habitat	Moderate-probability suitable habitats	High-probability suitable habitats	Total suitable habitat
RF[a]	4.62	0.37	0.11	5.09
SVM[b]	1.66	0.41	0.12	2.2
C5.0[c]	7.32	1.13	0.26	8.71
XGB[d]	1.73	0.88	0.69	3.31
GBM[e]	3.23	1.13	0.7	5.06

[a]*RF, random forest algorithm.*
[b]*SVM, support vector machine algorithm.*
[c]*C5.0, C5.0 algorithm.*
[d]*GBM, generalized boosted model algorithm.*
[e]*XGB, eXtreme gradient boosting algorithm.*

model, with another approaching the predicted high-probability suitable habitats. In addition, RF and SVM models predicted only two habitats.

DISCUSSION

O. hupensis is the only intermediate host of *S. japonicum* (Burton et al., 2019), and the *O. hupensis* survey is the most important part of schistosomiasis transmission risk monitoring (Gong et al., 2017; Huang et al., 2021). *O. hupensis* population expansion presents a specific pattern, widely influenced by climate factors such as ambient temperature, precipitation, and distribution of the river system. It may peak 2–3 years after colonization of *O. hupensis* populations after invading a new environment with a comfortable climate. It is very difficult to accurately identify the distribution of *O. hupensis* populations using conventional *O. hupensis* survey methods, which requires a large number of

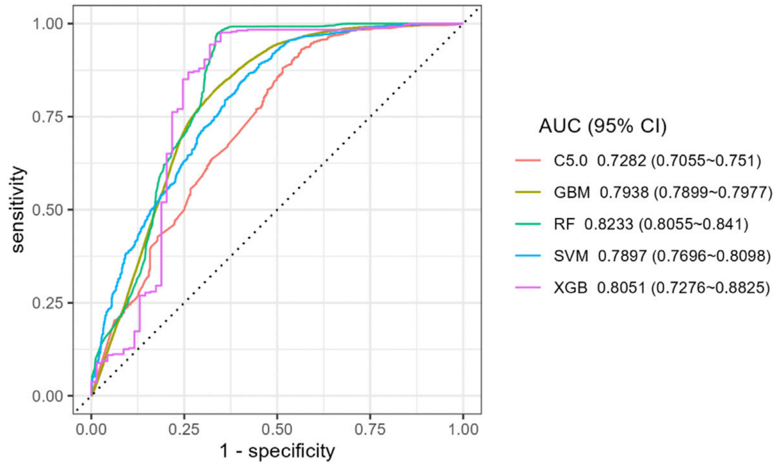

FIGURE 3 | Area under the receiver operating characteristic curve (ROC) of five ecological niche models. C5.0, C5.0 algorithm; GBM, generalized boosted model algorithm; RF, random forest algorithm; SVM, support vector machine algorithm; XGB, eXtreme gradient boosting algorithm.

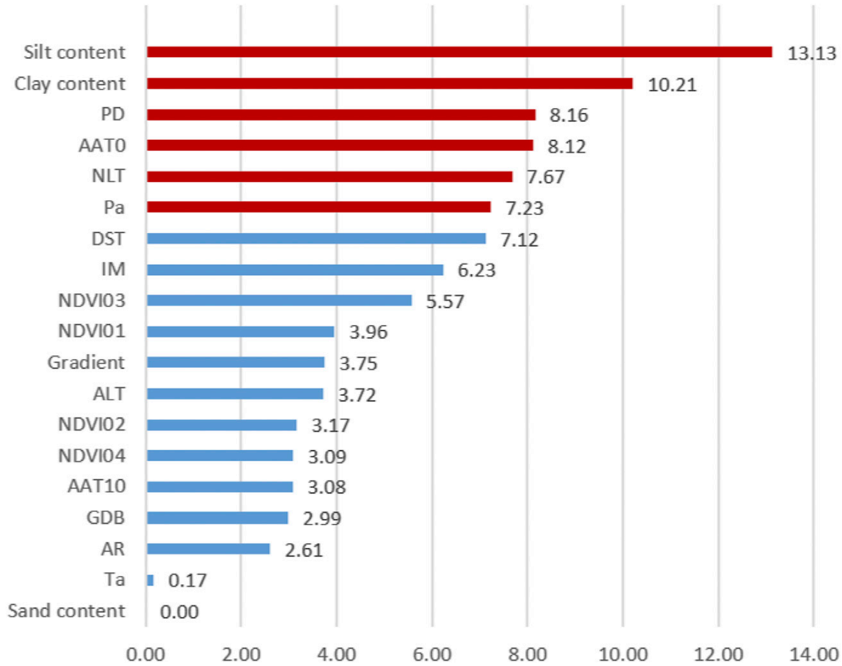

FIGURE 4 | Contributors to potential *Oncomelania hupensis* distribution.

manpower and material resources. Therefore, precise prediction of suitable *O. hupensis* habitats is of great significance for *O. hupensis* surveys.

In this study, using climatic and environmental variables, five machine learning algorithm models GBM, C5.0, XGB, RF, and SVM algorithms, predicted the potential distribution of *O. hupensis* in Suzhou City accurately, which may be used to guide and optimize *O. hupensis* surveys. The climatic and ecological variables, including temperature and precipitation, were usually considered to be the most important impact factors for the snail distribution and they play a decisive role in many big-scale studies (Gong et al., 2022). However, considering the difference in the microenvironment and it may affect the survival of the snail in a fine-scale study (Liu M.-M. et al., 2021), more environmental variables were picked up into machine learning algorithm models, including the silt content in soil, clay content in soil, population density, and night-time lights (Zheng et al., 2014; Gao et al., 2015), and

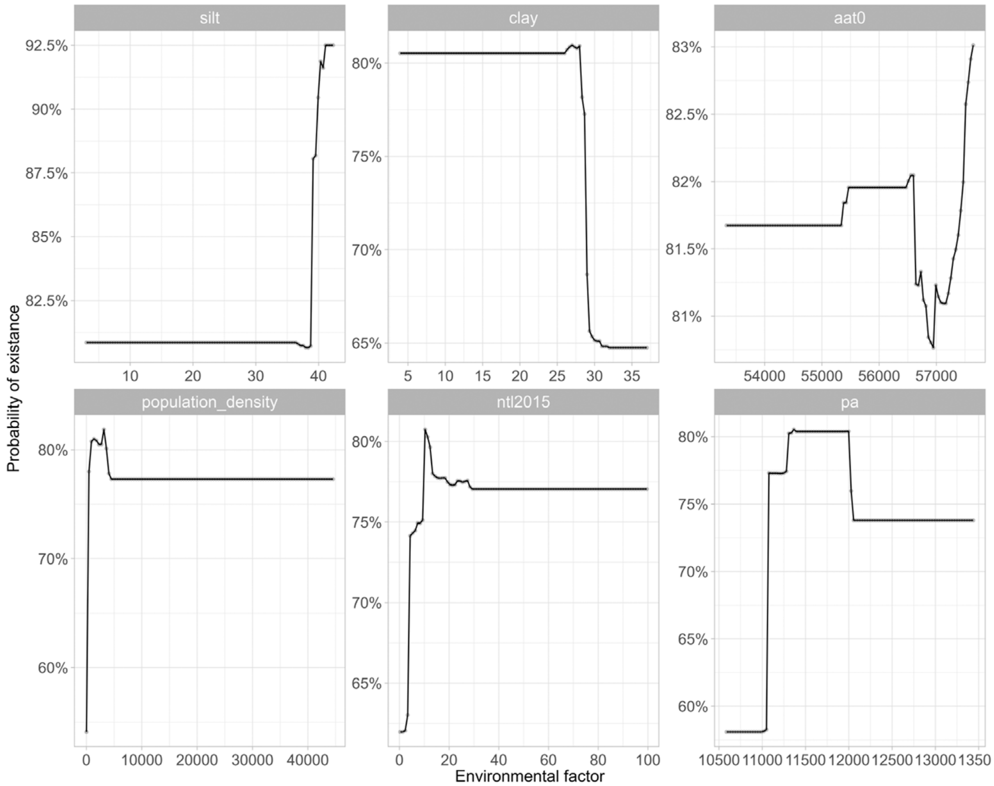

FIGURE 5 | Response curve of the six greatest contributors to potential *Oncomelania hupensis* distribution.

TABLE 4 | *O. hupensis* snail survey in 2021.

County	Township (street)	Village (community)	Area of *O. hupensis* survey (km^2)	Area of *O. hupensis* habitat (km^2)	Village (community) with *O. hupensis* habitat
Huqiu	7	28	1.973	0.010	Dasi of Dongzhu, Shifan of Zhenhu
Wuzhong	13	94	1.856	0.003	Yuli of Guangfu, Linwu of Jinting, Zhoushan of Xiangshan
Xiangcheng	8	225	1.734	0.000	--
Gusu	3	17	0.171	0.000	--
Wujiang	10	212	1.402	0.000	--
Industrial Park Region	4	43	0.582	0.000	--
Changshu	13	149	3.210	0.000	--
Zhangjiagang	7	12	0.050	0.000	--
Kunshan	11	161	2.043	0.000	--
Taicang	7	80	1.804	0.000	--
Total	83	1021	14.825	0.013	--

they show a significant contribution role for the *O. hupensis* distribution prediction in this study. These variables may have a direct or indirect effect on snail survival in a small-scale environment (Lackey and Horrall, 2021), and therefore, the prediction of five ecological niche models all showed AUC values of >0.7 for the prediction of potential *O. hupensis* distribution in Suzhou City, indicating a high predictive accuracy.

In the present study, based on the prediction of potential *O. hupensis* distribution by ecological niche models, conducting more surveys in high-probability suitable habitats of *O. hupensis* and fewer surveys in low-probability suitable habitats may allow the greatest likelihood for identification of *O. hupensis* habitats with the least workload. The predicted moderate- and high-probability suitable habitats were predominantly located in central and northern Wuzhong (Dongshan, Jinting, Guangfu, Xukou, Xiangshan, and Hengjing townships), southwestern Xiangcheng (Wangting Township) ,and central Huqiu (Zhenhu and Dongzhu townships). According to the 2021 *O.*

hupensis survey in Suzhou City, C5.0, XGB, and GBM models were found to have the greatest accuracy for the prediction of potential *O. hupensis* distribution. However, the C5.0 algorithm predicted the largest suitable habitats of *O. hupensis* (8.71% of total areas in Suzhou City), and only one of the five habitats with *O. hupensis* was located in the predicted high-probability suitable habitats. XGB and GBM models, which were also accurate in predicting the potential distribution of *O. hupensis* snails, seem more effective to improve the detection of *O. hupensis* and save manpower, material, and financial resources than the C5.0 algorithm. To compare the efficiency of six ecological niche models for the prediction of potential *O. hupensis* distribution Zheng (2021) calculated the AUC, accuracy, *Kappa* value, sensitivity, and specificity of the models, and the XGB model was found to show high accuracy, sensitivity, and specificity. In a recent study to estimate the AUC and true skill statistic (TSS) values of 10 ecological niche models, GBM, multivariate adaptive regression splines (MARS), and RF models were found to have better performance than other models (Hu, 2020). InGong's study, to predict the transmission risk of visceral leishmaniasis in the extension region of Loess Plateau, China, nine ecological niche models were used and RF and GBM models were reported to have higher predictive values (Gong Y. F. et al., 2021). In addition, GBM and RF models were found to present the greatest accuracy for fine-scale mapping of *O. hupensis* diffusion in Shanghai, and the prediction results by GBM and RF models were almost in agreement with field *O. hupensis* surveys during the recent years, which is consistent with our findings. Besides the AUC, Kappa value, a new statistical metric named DISO (Distance between Indices of Simulation and Observation) was developed to evaluate the overall performance of different models (Hu et al., 2019; Zhou et al., 2021). DISO will be employed in our future study to measure the different models' performance.

The high-probability suitable habitats of *O. hupensis* predicted by the five ecological niche models all covered Jinting and Dongshan townships of Wuzhong County, and these two high-probability suitable habitats are located in Xishan Island in Taihu Lake and along the margin of Taihu Lake in Dongshan Township. Previous studies have shown that ecological restoration projects may cause the re-breeding of *O. hupensis* (Mulieri and Patitucci, 2019; Wang et al., 2020; Gong Y. et al., 2021). Therefore, these two high-probability suitable habitats of *O. hupensis* should be given much attention. Even though no *O. hupensis* were detected along the margin of Taihu Lake in Dongshan Township in 2021, much attention should be paid during the 2022 *O. hupensis* survey. In addition, the five ecological niche models all predicted large suitable habitats of *O. hupensis* in Wujiang. There are plenty of lakes and rivers in Wujiang, and the water regions cover 267 km^2, accounting for 22.69% of total areas in Wujiang. On October 12, 2021, Wujiang was designated as a demonstration region of national ecological cultivation construction by the Ministry of Ecology and Environment of the People's Republic of China. Although low-probability suitable habitats of *O. hupensis* were predicted in Wujiang, high attention should be given to *O. hupensis* breeding. In terms of other infection diseases, with the global warming, the environment has been changed significantly, which plays a key role for the occurrence, transmission and outbreak of the infection disease (Wang et al., 2021). One health theory was proposed to develop a new system including human health, environmental health and animal health (Yang 2021; Lu 2021; Yang 2022). It provides a new approach to investigate the infection diseases according to the one health concept in future.

This study has three innovations. First, there have been few reports pertaining to fine-scale prediction of potential *O. hupensis* distribution based on ecological niche modeling. Second, field *O. hupensis* surveys were performed to validate the predictive accuracy of ecological niche models in this study. Therefore, our study offers more real and objective assessment. Third, our data may provide insights into the optimization of *O. hupensis* surveys. However, the current study has some limitations. The impact of geographical barriers on *O. hupensis* diffusion was not included in ecological niche models. Currently, the definition of ecological niche is mainly based on the BAM diagram, where B indicates biotic niche, A indicates abiotic niche, and M indicates movement (Liao, 2011; Alkishe et al., 2021). The biotic niche and abiotic niche jointly determine the suitable habitats of species; however, geographical barriers may restrict species diffusion (Hu, 2020). For example, GBM and XGB models predicted the high-probability suitable habitats of *O. hupensis* in Pingjiang, Guanqian, and Taohuawu of Gusu. Although there are lots of rivers in these blocks, concrete hardening is given along the river banks and vegetation is scattered along the streets, which forms barriers to directly affect *O. hupensis* diffusion. The inclusion of river modification and urbanization construction into ecological niche models may improve the accuracy of prediction of potential *O. hupensis* habitats, which deserves further investigation. Further studies to include geographical barriers data into ecological niche models seem justified.

CONCLUSION

In this study, ecological niche models were used based on five machine learning algorithms, including eXtreme gradient boosting (XGB), support vector machine (SVM), random forest (RF), generalized boosted (GBM), and C5.0 algorithms, to predict the 2021 potential distribution of *O. hupensis* with data from 2016 to 2020 in Suzhou, China. Comparing the predictive results and the truth, XGB and GBM models showed more effectiveness in the fine-scale prediction of potential *O. hupensis* distribution, which provides insights into the surveillance of *O. hupensis* snails. Based on the results, conducting more surveys in high-probability suitable habitats of *O. hupensis* and fewer surveys in low-probability suitable habitats may allow the greatest likelihood for identification of *O. hupensis* habitats with the least workload.

DATA AVAILABILITY STATEMENT

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

Study designing: QS, JZ, ZH, SL.Data curation: QS, JZ, JW, ZH. Data analyses: QS, YG and JZ. Writing— original draft: QS, ZH and SL. Writing—review & editing: ZQ, JZ, ZH, JW and SL.

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