Prediction of range expansion and estimation of dispersal routes of water deer (*Hydropotes inermis*) in the transboundary region between China, the Russian Far East and the Korean Peninsula

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Main Conclusions

- We analyzed water deer data from newly occupied areas in the transboundary region between China, Russia, and North Korea, and predicted suitable habitats and two possible dispersal routes connecting them. With this information, we provide a general understanding of the habitat use of this species and demonstrate the existence of connectivity for wildlife in the larger landscape, which can contribute to the conservation of the whole landscape, although it will need more effort to survey and protect.

Objectives

- Herbivorous animals play an important role in the ecosystem in terms of direct ecological interaction with animal predator and vegetation used for food. Water deer (*Hydropotes inermis*) is a species endemic to East China (Chinese water deer, *H.i. inermis*) and the Korean Peninsula (Korean water deer; *H. i. argyropus*). The water deer is listed as 'Vulnerable' at a global level by the IUCN Red List.
- There is an urgent need to understand the changes in habitat condition due to new expansions of population and predict the distribution of the expansions and the possible dispersal route. We hypothesize that the adequate habitat for water deer in and around the current region of expansion contributes to the northward expansion of this species.
- The objective is to understand the factors facilitating the range expansion of water deer. It is imperative to **understand the habitat preferences of the species** and **predict the range expansion** in order to guide management strategies for monitoring and research in the newly occupied areas.

Overview and Study site

- Our research area focused on the new expansion area including the southern regions of Liaoning, Jilin, and Heilongjiang provinces in China, the Primorye region in Russia, the whole of North Korea, and the northern part of South Korea.
- To predict water deer habitat suitability, we first need geolocated occurrence data, and so we collected 102 occurrence data in total from various sources.
- Considering the water deer ecology in southeast China and South Korea, seven main environmental variables were selected for habitat modelling.
- We used a MaxEnt model to predict water deer habitat characteristics, and the circuit method to analyze the conservation area network in the Tumen transboundary region.

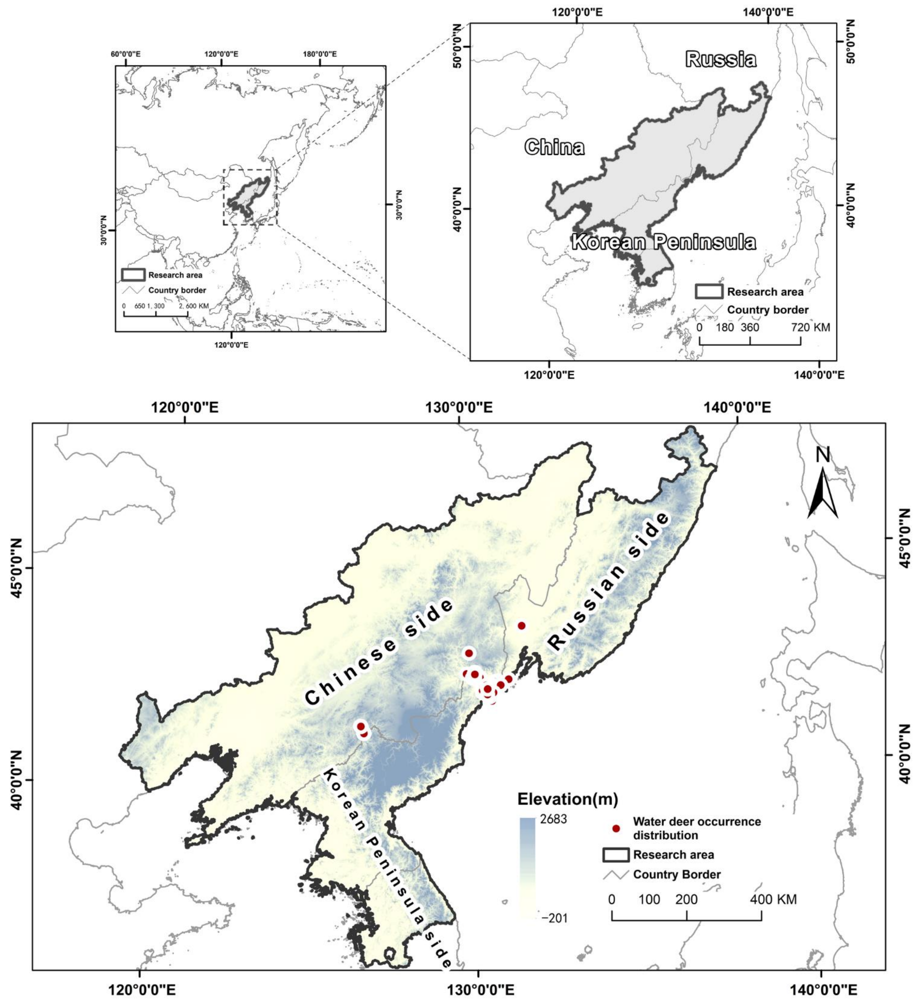

Fig 1. Locations of water deer occurrence used for modeling.

Methods

➢ Habitat Suitability

- We used **MaxEnt 3.4.1** software to build the model to predict habitat suitability.
- We uploaded the 75-occurrence points data and the 7 uncorrelated environmental
- variables to the software, and we set the output format as Logistic, using 25 percent species occurrence data as test data set.
- The ENMeval R package was applied to test the best model parameters by setting it to select the model with the most significant result, omission value less than 5%, and delta AICc value less than 2.
- The parameter setting used the linear, quadratic, and threshold features together, with the regularization multiplier value set to 0.9. We built the model with 10,000 background points and 10 bootstrap replicates. A Jackknife analysis was used to assess the contribution of environmental variables. The model performance was evaluated using a threshold-independent area under the curve (AUC) of the receiver operating characteristic curve (ROC). The Jenks method was employed to determine habitat suitability level using ArcGIS 10.3.

Variable category	Variable	Description	Reference
Landcover	Landcover	19 different land cover types	GLCLU
Topography	Altitude (DEM)	Elevation of site area(m)	SRTM
	Slope	Slope of site area (°)	
	Aspect	Aspect of the area (flat, north, east, west, south)	
Proximity	Distance to cropland	Distance to cropland (m)	GLCLU
	Distance to built-up	Distance to built-up areas (m)	
	Distance to water	Distance from rives, streams, and lakes (m)	OpenStreetmap

➢ Habitat Connectivity

- Habitat connectivity was analyzed to predict suitable habitat connections, using the Appling landscape connectivity analysis method ("Circuitscape").
- Connectivity was analyzed for three area with high-quality habitat, as defined using MaxEnt results. They were new expanding Tumen River region (TM1), East North Korea region (NK2) and West North Korea region (NK3). The newly occupied areas in the lower Tumen region were defined as target region TM1. The predicted high-value habitat in the west and east coasts of the Korean Peninsula, for which there are also records of water deer, were defined as regions NK2 and NK3 respectively.

Results

➢ Habitat Suitability

- The ROC curve of the model had an AUC value of 0.935±0.014, indicating that our model could accurately simulate the relationship between the geographical distribution of water deer and the factors analyzed. The three most important variables selected for the model were elevation and distances to cropland and water source.

Variable	Percent contribution	Permutation importance
DEM	**59.6**	**64.8**
Distance to cropland	**16.3**	**13.4**
Landcover	10.8	5.9
Distance to water	**8.8**	**10.4**
Slope	2.1	3
Aspect	1.6	1.8
Distance to built-up	0.7	0.7

- The habitat with the highest suitability was mainly found in three areas. One comprised of the west coast of the Korean Peninsula, stretching into the southern Liaoning province in northeast China. The second was found along the east coast of the Korean Peninsula, ranging to the north of the Russian Far East coastal area.
- Some of the high-quality habitat was inside the protected area of China's Northeast Tiger and Leopard National Park and the neighboring Land of Leopard National Park in Russia, at the same time, some suitable habitat downstream of the Tumen River was not included in any protected area.

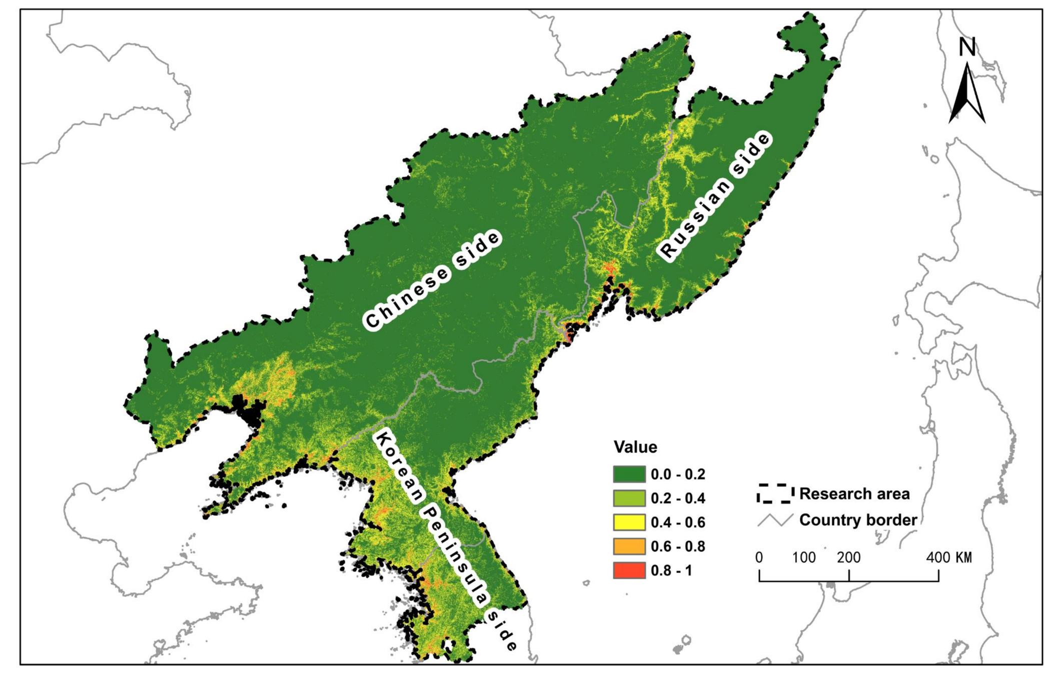

Fig 2. Maximum entropy model of habitat suitability for water deer (AUC = 0.939±0.011). The high suitability region (0.4–1) located along the Korean Peninsula's east and west coasts towards northeast China and the Russian Far East.

➢ Habitat Connectivity

- Route A possibly passes north of South Pyongan province and South Hamgyong province to Chagang province and passes the border between China and North Korean south of the Baishan area and through Linjiang, Fusong, and south of Antu, Wangqing, and Hunchun before reaching region TM1 downstream of the Tumen River region and connecting region NK2 to region NK3.
- Route B connected the habitat between regions NK3 and TM1, whereas South Hamgyong Province, except the eastern area, connected to North Hamgyong province, through Ryanggang province and the border area between China and North Korea, and passes the northern area of North Hamgyong province to the north and connected to the region downstream of the Tumen River

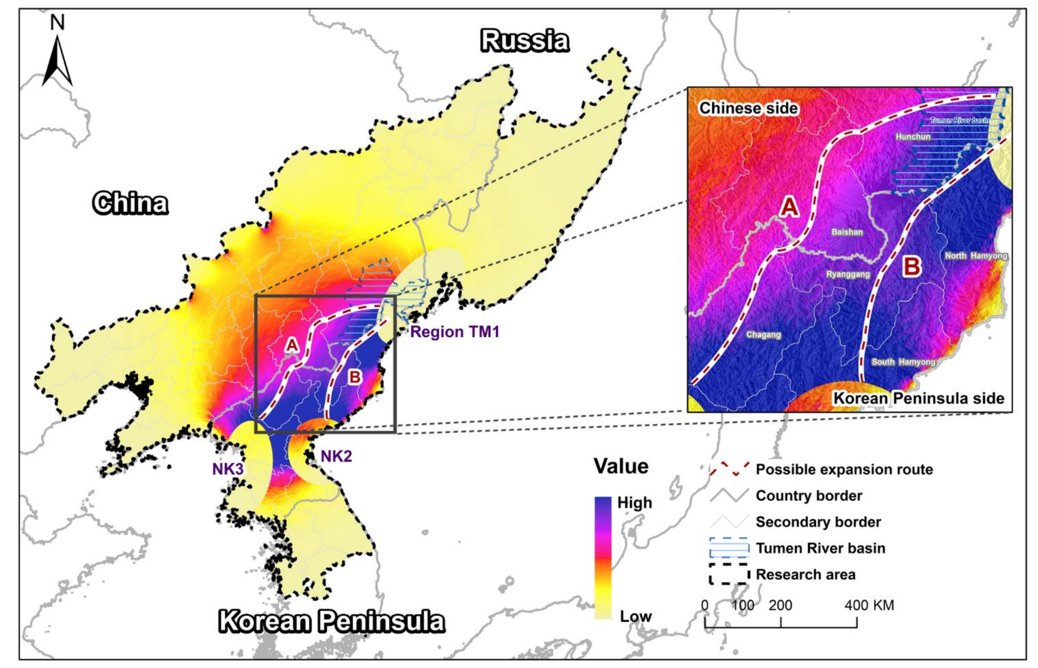

Fig.3. Possible dispersal routes of water deer. We calculated the connectivity between the suitable habitat patches for the regions in TM1, NK1 and NK2 and two possible routes, route A crosses North Korea and into China reaching the patch TM2, and route B crosses the east of North Korea and into the region TM1.

Discussions

- Based on our results, beyond the current occurrence area, suitable habitat extends to the north in the Russian Far East, where there is lower human pressure as well as good water resources and vegetation available.
- The water deer dispersal route may provide insights for the conservation of big cats. The Changbai mountain region was predicted to be an important potential habitat for the recovery of an isolated Amur tiger population, and the connectivity between habitat patches is crucial for the success of their conservation.
- Climate change and human activities drive species dispersal from one site to another. A connected landscape for wildlife movement and survival reduces the risk for species facing threats in a single region, as well as mitigates pressure from environmental influence. Conservation planning needs to move from a single site approach to one that can incorporate processes at landscape level.
- In the case of water deer dispersal, a transboundary biodiversity conservation plan needs to be considered, as landscape connectivity in the whole region will contribute to the health of forest and wetland ecosystems.