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New record of a blood-feeding terrestrial leech, *Haemadipsa rjukjuana* Oka, 1910 (Haemadipsidae, Arhynchobdellida) on Heuksando Island and possible habitat estimation in the current and future Korean Peninsula using a Maxent model

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To build a distribution model for *Haemadipsa rjukjuana*, we collected current occurrences of the species on Heuksando with adjacent islands. Based on current locations and 19 climate variables with DEM (digital elevation model), we built the MaxEnt (maximum entropy) species distribution model for *H. rjukjuana* in the islands. Then, we applied the MaxEnt model to the mainland of Korea with the current climate condition and topology. In addition to the current distribution scenario, we predicted the future distribution scenarios in Korea by Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate models. Shared Socioeconomic Pathway (SSP) 585 of two CMIP6 models (GISS-E2-1 and INM-CM4-8) from 2040 to 2100 were used for the future projection.

Keywords: CMIP6, *Haemadipsa rjukjuana*, Heuksando Island, MaxEnt, terrestrial leech

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In South Korea, the terrestrial leech has been never reported until *Haemadipsa rjukjuana* was recorded from Gageodo Island, which is located in the Yellow Sea (Seo *et al*., 2013). Blood-feeding terrestrial leeches are distributed in tropical and subtropical regions, and the family Haemadipsidae originated from Gondwana (Borda *et al*., 2008). *Haemadipsa rjukjuana* is primarily distributed in the Indo-Chinese Peninsula, Malay Peninsula, Indonesia, Ryukyu Islands, and Taiwan (Lai *et al*., 2011). The habitats of blood-feeding terrestrial leeches are restricted to damp forests with high humidity (Lai *et al*., 2011).

Regardless of terrestrial or aquatic species, the major strategy of dispersal for leeches is using host species, and leeches can move long distances when they parasitize migrating birds (Davies *et al*., 1982; Siddal *et al*., 2013). Gageodo Island and Heuksando Island have been known as important stopovers for migratory birds (Seo *et al*., 2015).

The first report of blood-feeding terrestrial leeches in Korea attracted attention. Seo *et al*. (2013) raised concern about the range expansion of *H. rjukjuana* in Korea like *Haemadipsa* spp. in Japan. However, additional studies on the species have been rarely implemented except for some molecular studies on parasitology (Won *et al*., 2014; Kang *et al*., 2016).

We surveyed Heuksando Island (6^{th}–7^{th}), Hongdo Island (8^{th}), and Jangdo Island (9^{th}) from 6–9 August 2022 (Fig. 1) and collected *H. rjukjuana* only from Heuksando Island. We identified the species based on the description by Seo *et al*. (2013) and specimens were fixed in 10% formalin for 3 days and stored in 70% ethanol. All collected locations and observed locations were geo-referenced by a GPS (Global Positioning System) device (Garmin GPS-V model). With the coordinates of the leeches, current 19 bioclim data (www.worldclim.org), and DEM (digital elevation model), we built a species distribution model of *H. rjukjuana* in Heuksando Island using MaxEnt software (version 3.4.4). Since building a distribution model with the current dataset is a type of machine learning for different spatial or temporal conditions, we projected the distribution model to mainland of South Korea in the current climate and future climate scenarios of SSP 585 (GISS-E2-1G by NASA, USA and INM-CM4-8 by The Institute of Numerical Mathematics, Russia) for 2040, 2060, 2080, and 2100 respectively.

The most important environmental variable for *H. rjuk-*

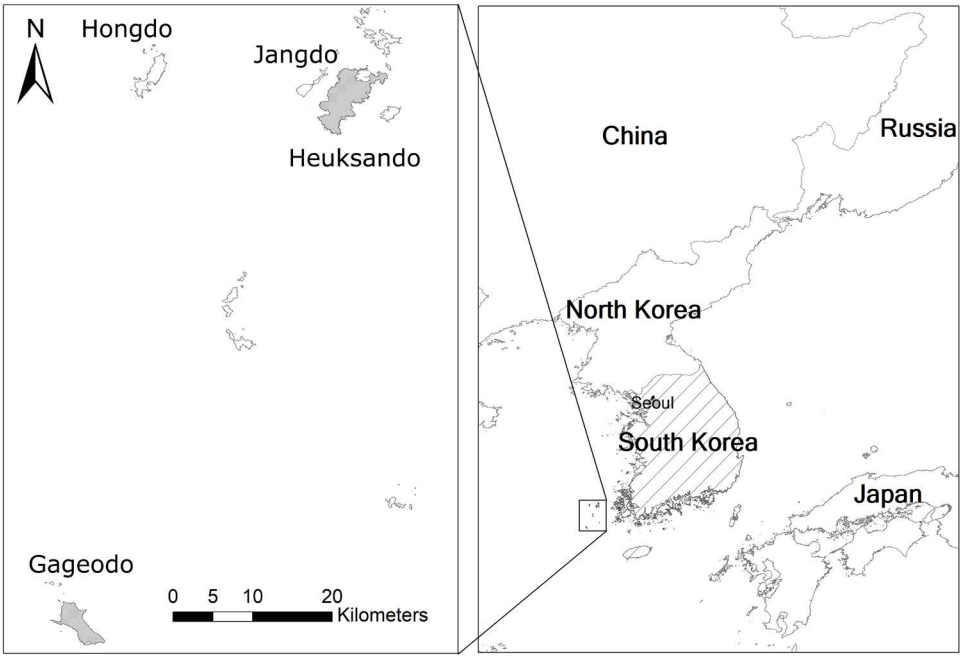

Fig. 1. The map of study sites (inset) and the Korean Peninsula. *Haemadipsa rjukjuana* was identified from the regions shaded in gray.

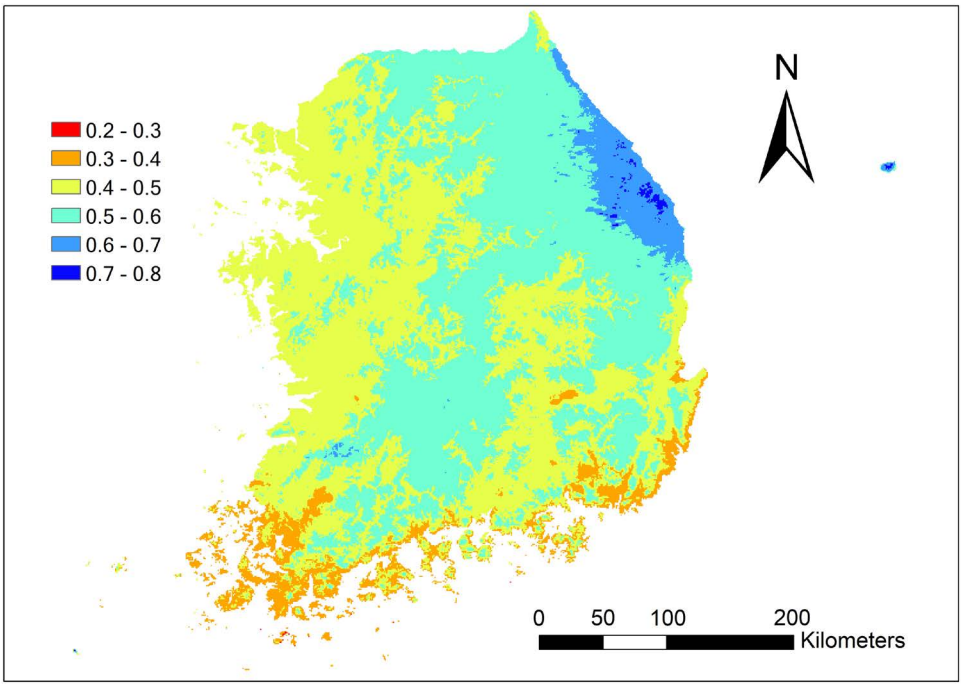

Fig. 2. Projection of MaxEnt *Haemadipsa rjukjuana* distribution model from Heuksando Island and Gageodo Island to the current climate condition of South Korea. Red color (lower value) represents less suitable habitats and blue (higher value close to 1.0) represents suitable habitats for *H. rjukjuana*.

juana in the islands was precipitation of driest month (B14) with 39.4% of contribution value (AUC [Area under the Receiver operating characteristic Curve] = 0.64). Other important variables were altitude (28.7% of contribution value), annual mean temperature (14.1%), mean temperature of coldest quarter (8.2%), and mean temperature of driest quarter (1.5%). The contribution values of other variables were below 1%. The lowest MaxEnt value of

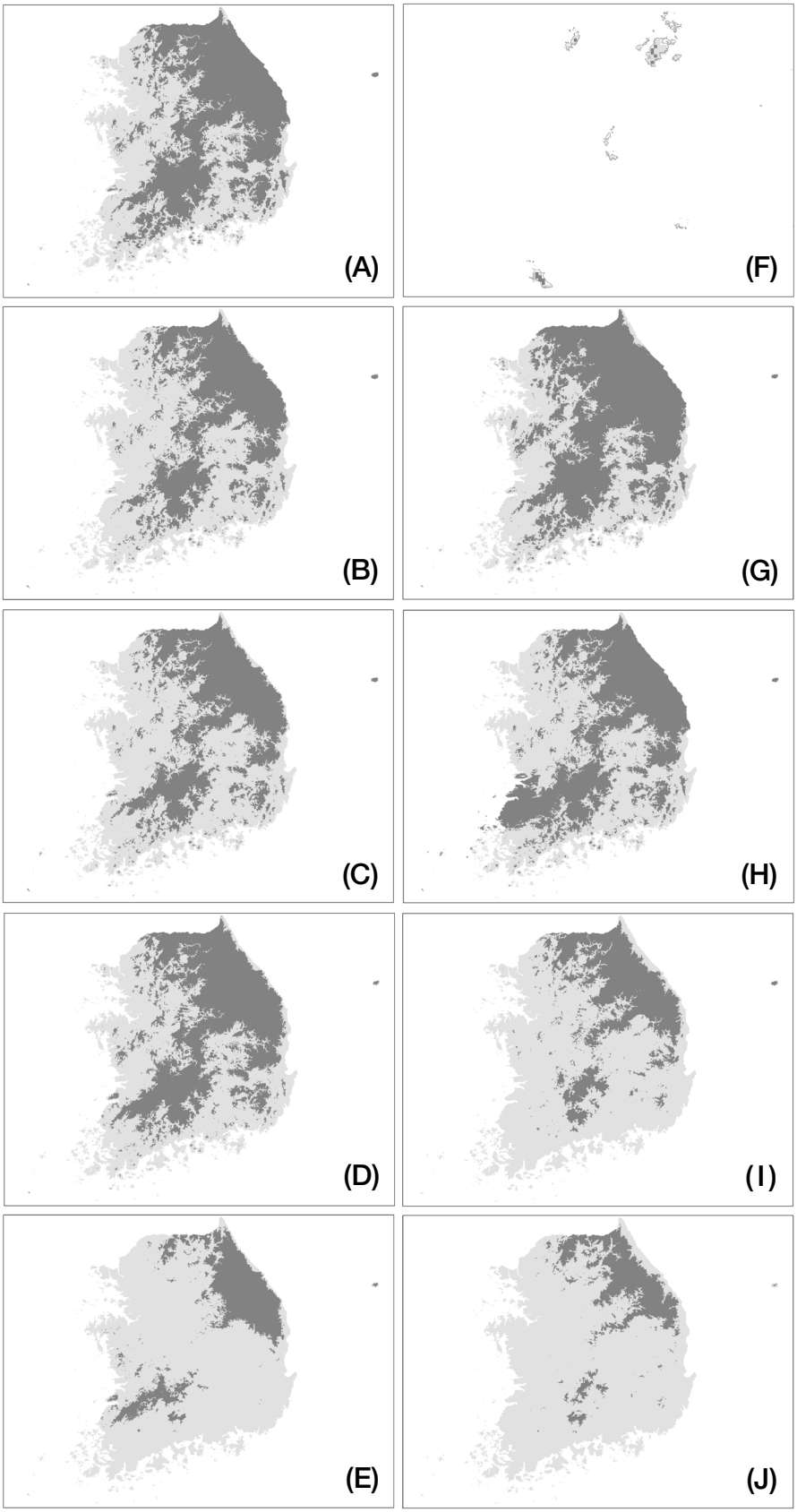

Fig. 3. Current (A and F) and future distribution models (B–E, G–J) for *Haemadipsa rjukjuana* in Korea. Dark gray represents over 0.5 MaxEnt value (suitable habitat) and light gray represents below 0.5 (unsuitable habitat). A is projected to the current climate conditions (2020), and F was built with the restricted spatial area between Heuksando Island and Gageodo Island. B–E are projections of the Maxent model to SSP585 of GISS-E2-1 climate scenarios by NASA and G–J were SSP585 of INM-CM4-8 scenarios by The Institute of Numerical Mathematics. B–E and G–J are respectively 2040, 2060, 2080, and 2100.

H. rjukjuana in Korea was 0.199 and highest was 0.739 (MaxEnt value 1 is suitable habitat and value 0 is unsuitable). Based on the MaxEnt model from Heuksando Island and Gageodo Island, 48.26% of South Korea showed over 0.5 value (Fig. 2).

According to future scenarios of SSP 585 of GISS-E2-1, the ratio of suitable habitat (over 0.5 of MaxEnt value) of *H. rjukjuana* in Korea were 38.65% in 2040, 38.28% in 2060, 43.73% in 2080, and 17.96% in 2100 (Fig. 3). In other hands, SSP 585 of INM-CM4-8 scenarios predicted 52.79% in 2040, 44.15% in 2060, 25.16% in 2080, and 13.91% in 2100 (Fig. 3).

Although MaxEnt is a presence-only model for species distribution, the model is relatively accurate and can predict different spatial and temporal distributions with future climate scenarios (Jo *et al*., 2017). According to our model, we can expect more possible habitats of *H. rjukjuana* in the mainland of Korea. Japan has already experienced a range expansion of *Haemadipsa* sp. since the 1990s (Aizawa and Morishima, 2018). If this leech species arrives on the mainland of Korea, it is expected that the blood-feeding terrestrial leech could survive in about half of the country in the current climate condition. Fortunately, the future climate scenarios in South Korea were not favorable for the foreign species. Although SSP 585 of INM-CM4-8 predicted the increased suitable habitat until 2040, all other scenarios predicted the decreased suitable habitat for the species in the mainland of Korea.

Still, the dispersal ability of *Haemadipsa* spp. is poorly understood (Drinkwater *et al*., 2020). How *H. rjukjuana* arrived on the western islands is unclear, but it is plausible that migratory birds brought the parasite leeches to the island. Since we could not identify *H. rjukjuana* from Jangdo Island and Hongdo Island, which are located close to Heuksando Island, respectively 900 m and 17 km apart, the dispersal of the terrestrial leech seems an accidental event rather than gradual movement depending on distance. Due to the passive movement of leeches by host species (Nakano *et al*., 2020), the distribution of leeches in the islands in the Yellow Sea should be decided not by leeches but by birds.

At this time, Gageodo Island and Heuksando Island are the only places in South Korea with a known occurrence of the blood-feeding terrestrial leech. However, the leech species could arrive on the mainland of Korea by either anthropogenic or natural causes, especially through birds. Since the leeches can travel with migratory birds (Davies *et al*., 1982; Siddal *et al*., 2013), there is no barrier against bird flyways. Under the current climate conditions, if the leech species is introduced into the mainland of Korea, it is highly plausible that the hematophagous land leech becomes a new member of the ecosystem in the Korean Peninsula. With discomfort, swelling skin, and itching, the novel blood-sucking animal, which has never occurred before in Korea, should cause public fear (Ngamprasertwong *et al*., 2005). To prepare for the invasion by the terrestrial leech species, more research on the natural history of *H. rjukjuana* with vigorous monitoring is required.

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