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Current Distribution and Status of Non-Native Freshwater Turtles in the Wild, Republic of Korea

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Abstract: Globally, an increase in the transportation and expansion of the pet market is the most important cause of the invasion of non-native species. Invasion of non-native species disturbs native ecosystems and leads to socio-economic problems. The pet trade involving turtles has been globally recognized as the route through which non-native species enter ecosystems. As a result, the invasion of non-native turtles worldwide is causing problems such as competition, predation, transmission of parasites, and hybridization with native turtles. Every year, both the number of non-native turtles imported as pets in the Republic of Korea and the number of introduced species found in the wild is increasing. However, the current status of non-native turtles in the wild is not well known, posing major challenges to their management. In this study, we aimed to determine the current status of non-native turtles introduced into the wild in Korea. We analyzed the factors associated with the detection and distribution of non-native turtles. In total, 1587 of non-native turtles (three families, six genera, and 13 species including subspecies) were found in 648 sites in Korea: *Chelydra serpentina*, *Mauremys sinensis*, *Chrysemys picta bellii*, *Graptemys ouachitensis*, *G. pseudogeographica pseudogeographica*, *G. p. kohni*, *Pseudemys concinna*, *P. nelsoni*, *P. peninsularis*, *P. rubriventris*, *Trachemys scripta elegans*, *T. s. scripta*, and *T. s. troostii*. There was relationship between the distribution of non-native turtles and environmental factors such as precipitation and temperature. Moreover, human factors such as number of human populations and size of region were significantly related with the distribution and number of non-native turtles. In conclusion, it is likely that human factors are associated with the influx of invasive turtles to the natural habitat, while the possibility of survival and adaption for the turtles is associated mainly with environmental factors. Our result will be an essential guideline not only for understanding the current status of non-native turtles in Korea, but also for establishing strategies for management and control.

Keywords: invasive species; reptiles; human factor; environmental factor; national survey

1. Introduction

Recently, the increase in invasion by non-native species has become a global issue. Non-native species may cause severe damage to native ecosystems and biodiversity [1,2], and often incur substantial costs to control them [3–5]. This introduction of non-native species is related to the increase in traffic and the expansion of the pet market [6], and is likely to be a more serious problem in the future.

In addition to the red-eared slider (*Trachemys scripta elegans*), which is included in the list of the world's worst top 100 invasive species [7], numerous reptiles have been imported as pets and

introduced to native ecosystems [8,9]. Non-native turtles settled in natural environments spread rapidly to impact the native ecosystem [10] through competition [11,12], propagation of parasites [13], and hybridization with native species [14].

The import of red-eared sliders for the pet trade in South Korea began in the late 1970s [15]. More than one million turtles were imported and sold throughout the country, a large proportion of which were either abandoned by former owners or released to the wild for religious purposes [15]. Subsequently, the import of red-eared sliders was banned, and the turtle was designated as an ecological disturbance species in Korea [16]. However, red-eared turtles have since been established in the wild in Korea [9,17]. After the ban of red-eared slider imports, other non-native turtles were imported for the pet trade [16]. Recent field survey found red-eared sliders and these other non-native turtles in the wild, with their numbers steadily increasing [18,19].

Field surveys have been conducted by the South Korean government to determine the current distribution of non-native turtles [16,20–22]. However, the previous surveys only reported the list of non-native species without further analysis. As a result, these nationwide surveys are not informative for understanding the current status of non-native turtles in Korea.

Here, we report on the current distribution and status of non-native turtles in the Republic of Korea. In addition, we tested our hypothesis that the distribution of non-native turtles in Korea is more closely associated with human factors than the environmental factors. Our results will be informative in providing a guideline for the management of non-native turtles in Korea.

2. Materials and Methods

2.1. Distribution of Non-Native Turtles

We collected all available data on the distribution of non-native turtles produced in the Republic of Korea. We included the data presented in the "National Ecosystem Survey" and "Nationwide Survey of Non-Native Species in Korea" conducted by the Korean government, in addition to the survey results by individual researchers (see Supplemental Materials S1 for details). The National Ecosystem Survey, conducted from 2007 to 2013, divided Korea into 824,155.7 km^2 (11.2 km × 13.9 km) rectangular areas for a survey of the entire area by reptile experts [23]. The Nationwide Survey of Non-Native Species in Korea, conducted from 2015 to 2018 in all Korean cities and counties, assessed the distribution of all non-native species found in Korea [16,20–22]. All surveys were conducted according to the "Guidelines for the 4^{th} National Natural Environment Survey" by the National Institute of Ecology [24].

2.2. Analysis of Factors Associated with Distribution of Non-Native Turtles

We analyzed the factors associated with the distribution of non-native turtles. The two main factors, environmental and human conditions, were considered for the analysis. Environmental factors included (1) altitude and (2) climatic variables (t_{mean} is the average monthly mean temperature; t_{min} is the average monthly minimum temperature; t_{max} is the average monthly maximum temperature; prec is the average monthly precipitation) in each habitat (Table A1) [25]. Climatic variables were collected from Worldclim (ver 2.0) with the mesh size of 30 s (0.93 x 0.93 = 0.86 km^2 at the equator). We used ArcGIS 10.6 (ESRI, USA) to obtain the climate data at each location. Human factors included (1) size of the human population, (2) geographical size of region (km^2), (3) income per capita (Korean Won converted to Dollars for 1000 = 0.83 ratio), and (4) human population density (size of human population/size of region) in the locations where non-native turtles were found (Table A2). For the number of human population and the size of region, we used the data collected by the population census conducted in 2018 [26]. In the case of income per capita, we used the data collected by the survey of the whole nation conducted in 2017 [26].

2.3. Statistical Analysis

To test the effect of environmental factors on the distribution of non-native turtles, we used a negative binomial generalized linear model (GLM) with the number of turtles at the site as the response. All predictors were centered and normalized. To address collinearity between covariates, we extracted the first three principal components from the principal component analysis (PCA), explaining 95% of the total variance, to use as predictors.

The relationship between human factors and distribution of non-native turtles was analyzed with a negative binomial GLM with the number of sites in the region as the response. To address the correlation between population density and both population and size of region, we constructed a full model by replacing population density with a two-way interaction between population and the size of region, and conducted model selection using AICc for this full model and all nested models. All predictors were centered and normalized. We used the MASS [27] and MuMIn [28] package in R 3.6.1 [29] for the analysis.

3. Results

3.1. Distribution of Non-Native Turtles

A total of 1587 non-native turtles (three families, six genera, 13 species including subspecies) were found at 648 locations in the wild (Table 1, Figures 1 and 2). The genus *Trachemys* was found in the largest number (1113 turtles) in the greatest number of locations (450 sites). The number of locations and individuals were 176 and 419 for the genus *Pseudemys*, and 22 and 53 for all other genera including the genus *Graptemys*, respectively. At the species level, the number of locations (407 turtles, 62.8%) and individuals (1028 turtles, 64.9%) of *T. s. elegans* was higher than that of other species (Table 1).

Table 1. The list of non-native turtles found from the wild in the Republic of Korea.

Family	Species	Location		Individual	
		n	%	n	%
Chelydridae	*Chelydra serpentina*	1	0.2	1	0.1
Geoemydidae	*Mauremys sinensis*	17	2.6	46	2.9
Emydidae	*Chrysemys picta bellii*	1	0.2	1	0.1
	Graptemys ouachitensis	1	0.2	1	0.1
	Graptemys pseudogeographica kohni	1	0.2	2	0.1
	Graptemys p. pseudogeographica	1	0.2	2	0.1
	Pseudemys concinna	79	12.2	220	13.9
	Pseudemys nelsoni	27	4.2	66	4.2
	Pseudemys peninsularis	41	6.3	87	5.5
	Pseudemys rubriventris	29	4.5	46	2.9
	Trachemys scripta elegans	407	62.8	1028	64.9
	Trachemys scripta scripta	33	5.1	66	4.2
	Trachemys scripta troostii	10	1.5	19	1.2
	Total	648		1585	

3.2. Relationship between Number of Turtles and Environmental Factors

Mean temperature where non-native turtles were found was 12.6 ± 0.1 °C (range: −6.9–26.7). The minimum and maximum temperatures were 7.6 ± 0.1 °C (−12.4–23.0) and 17.5 ± 0.1 °C (−1.5–32.4), respectively. Precipitation was 107.2 ± 1.0 mm (14.0–341.0) and altitude was 68.0 ± 3.0 m (0–673) (Table A1). The second and third principal components of the environmental factors were associated with the number of turtles at the site (Table 2). The second principal component is correlated strongly with precipitation, while the third principal component is correlated with temperature and altitude (Figure A1).

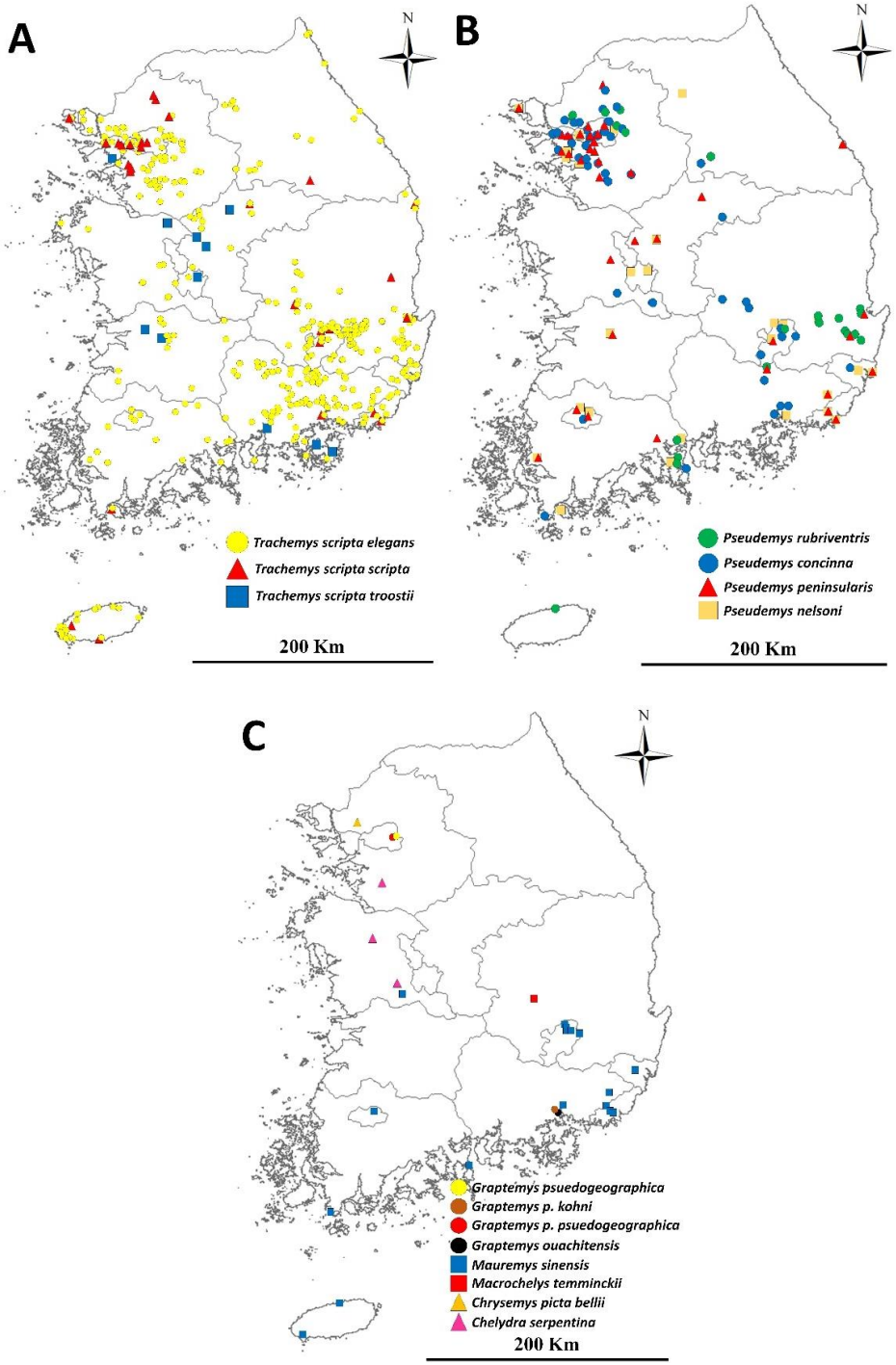

Figure 1. Distribution map of non-native turtles in the Republic of Korea. Species in (**A**) *Trachemys*, (**B**) *Pseudemys*, and (**C**) other genera.

Table 2. The effect of environmental factors to the number of non-native turtles, analyzed with a negative binomial GLM (generalized linear model). All P-values were obtained from the Wald approximation.

Predictor	Estimate	SE	P
PC1	−0.0373	0.0326	0.2525
PC2	0.0912	0.0336	0.0066
PC3	0.0855	0.0330	0.0095

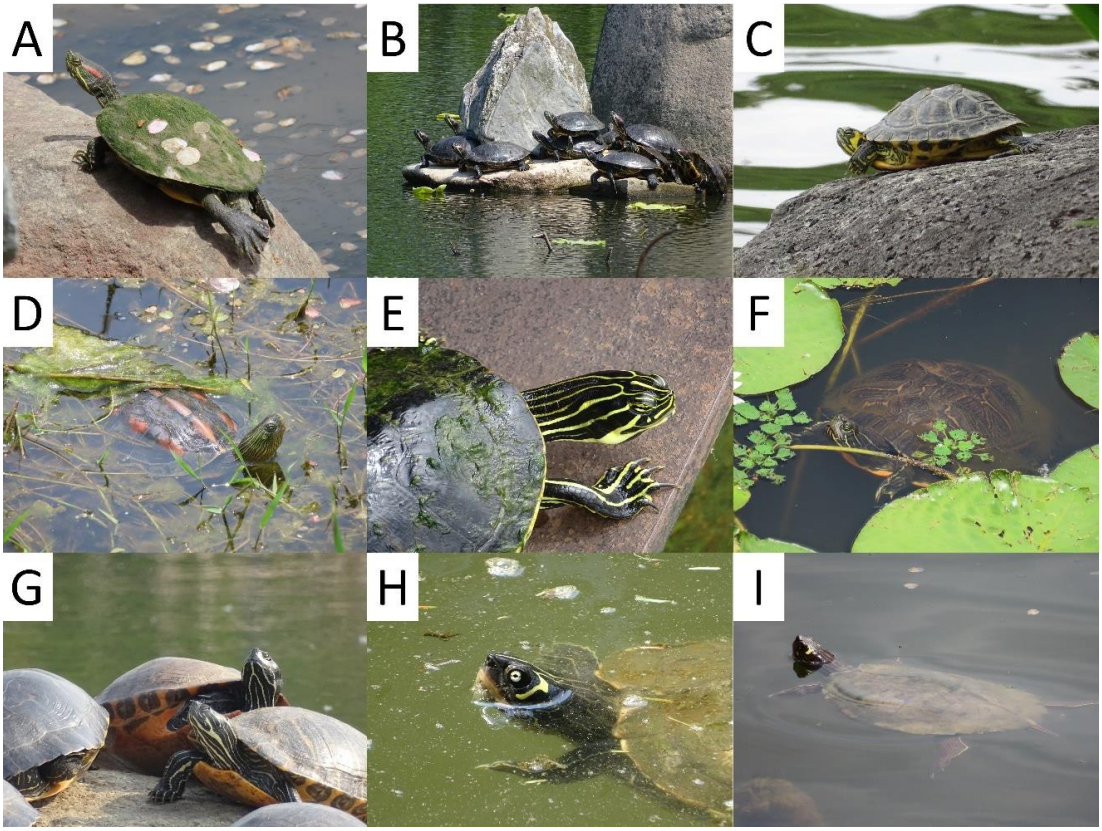

Figure 2. Non-native freshwater turtles in the Republic of Korea. (**A**,**B**) Trachemys scripta elegans, (**C**) Trachemys scripta scripta, (**D**) Mauremys sinensis, (**E**) Pseudemys peninsularis, (**F**) Pseudemys concinna, (**G**) Pseudemys nelsoni, (**H**) Graptemys pseudogeographica kohni, (**I**) Graptemys ouachitensis. Photo by Kyo Soung Koo.

3.3. Relationship between Non-Native Turtles and Human Factors

The best model selected by AICc outperformed the full model (Table 3; ΔAICc = 11.05) and included the population and the size of the region as covariates, with both population and size of region being positively correlated with the number of turtles, while per capita income and human population density, which corresponded to the interaction term between the population and the size of reason, was dropped from the model (Table 4).

Table 3. Model selection table for the relationship between the number of non-native turtles and human factors. DF: degree of freedom; LogLik: log likelihood.

Model	DF	LogLik	AICc	ΔAICc	Weight
Population + Size of Region	4	−61.45	135.34	0	0.41
Size of Region	3	−64.26	136.93	1.59	0.18
Population	3	−64.57	137.54	2.20	0.14
Income + Population	4	−62.82	138.08	2.74	0.10
Population + Size of Region + Population*Size of Region	5	−61.24	139.98	4.64	0.04
Income + Population + Size of Region	5	−61.38	140.26	4.92	0.03
Income	3	−66.01	140.42	5.09	0.03
Income + Size of Region	4	−64.02	140.49	5.15	0.03
(null)	2	−67.72	140.53	5.19	0.03
(full model)	6	−61.20	146.39	11.05	0

Table 4. Estimates from the best model for the relationship between the number of non-native turtles and human factors.

Predictor	Estimate	SE	P
Population	0.5090	0.1947	0.0089
Size of Region	0.5143	0.1950	0.0083

4. Discussion

About 26 million red-eared sliders were imported from 1988 to 1994 into the Republic of Korea [15]. However, a large number of turtles were either abandoned by the pet owners or deliberately released into the wild in religious events, resulting in their introduction to the Korean natural ecosystem [30]. More than 20 years after an import prohibition, the red-eared sliders have adapted to the Korean climate and ecosystem. It was confirmed that the introduced red-eared slider reproduced in the wild in Korea [9,31]. Previous ecological surveys also showed that red-eared sliders are present in larger numbers and in more locations than other species. These observations suggest that the range of red-eared sliders are expanding in Korea [31]. High priority must therefore be given to the control of red-eared sliders introduced into Korea, especially localized control and management over the region where natural breeding is confirmed.

After imports of the genus *Trachemys* including red-eared sliders was prohibited with their designation as an ecological disturbance species in 2001, the import of cooters (*Pseudemys conncina*) began [15]. The river cooter is a freshwater turtle that is sold in pet shops and over hundreds of large retail stores at low prices throughout the country [6]. The price and availability of the river cooter increase the possibility of their being eventually introduced into the wild. We have found that the river cooter (*P. conncina*) in the genus *Pseudemys* was the second most frequently found turtle after the red-eared slider. In particular, cooters have been found to lay eggs in public parks, even though they subsequently failed to hatch (unpublished data), which indicates that the river cooter may be adapting to the Korean environment.

In other countries where the cases of releasing non-native species in Buddhist religious events is customary, this practice was correlated with the income of local residents [27,32] even though the frequency of releases differed according to the region [27]. In Korea, the red-eared slider was released in similar religious events in the past, and this is still practiced with other species of non-native turtles being released into the wild. In accordance with these studies, we found that the occurrence of non-native turtles was associated with a larger human population, greater geographical area, and higher per-capita income of local residents, with a variety of species and a large number of non-native turtles found in Seoul and Gyeonggi Province.

The long lifespan and large size of adult turtles resulted in many pet turtles being abandoned by previous owners [18,33]. The tendency to abandon pet turtles is a significant factor contributing to the influx of non-native species into the wild. For turtles released in religious events, it was previously reported that local residents with higher education were less likely to release non-native species into the wild [32]. Informing pet owners about the problems associated with non-native turtles, along with establishing shelters for abandoned pet turtles, may be helpful to reduce the number of turtles being released into the wild.

The distribution of non-native turtles in Korea was associated with both environmental and human factors. Human factors are associated with the influx of non-native species to the environment [19], especially to artificial releases and abandonments of individuals formerly raised by humans. On the other hand, temperature and precipitation, the two main environmental factors associated with the distribution of turtles, are likely to influence the survival of turtles in the wild. Precipitation heavily influences the survival and reproduction of turtles [34,35], and contributes to the availability of suitable habitats [36], especially for freshwater turtles such as the non-native species found in Korea. Temperature is also associated with then reproduction and hibernation of turtles [34,35]. The large

number of species found in the wild in South Korea, in addition to the observation that red-eared sliders and river cooters were able to reproduce in the wild (unpublished data), suggest that the turtles are able to survive and reproduce in the wild in these habitats [9,19,37,38].

Of the 13 species of non-native turtles found in this study, three species in the genus *Trachemys* are designated as species that cause ecological disturbances [15]. Since these species are legally controlled species, their import, breeding, and sale are strictly prohibited by law [15]. However, private entities may import, transport, and sell the non-native turtle species not included in the list of endangered species, CITES (Convention on International Trade in Endangered Species of Wild fauna and flora), or ecological disturbance species, and these activities are not tracked by government agencies. This legislative oversight results in the unreported, indiscriminate import of non-native turtles. According to the Ministry of Environment, a total of 304 species of reptiles were imported into Korea, 34% (120 species) of which were turtles [16]. Moreover, the import of the non-native Ouachita map turtle (*Graptemys ouachitensis*), which was found in the wild in Korea, was never reported to government agencies [16,19]. Even though the number of turtle species imported without official records are not available, these imports pose a great problem in managing and responding to the influx of non-native species. It will be necessary to prohibit the import of exotic turtles without informing government agencies to reduce the influx of non-native species into the wild.

In this study, we reported on the distribution of non-native turtles in the Republic of Korea, and identified the factors associated with their occurrence. These results will fill the gap in the information upon the current distribution of non-native species in the world, and also highlight the importance of human behavior on the introduction of invasive species through the pet trade. Thirteen species of non-native turtles have been discovered so far, with the number of species likely to increase in the future. For a more collaborative, more effective effort to control the spread of non-native turtles, further research into the distribution and ecology of invasive turtles will be pivotal.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/10/4042/s1, Table S1: Distribution of non-native turtles in Republic of Korea.

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Conflicts of Interest: The authors declare that they have no conflicts of interest.

Appendix A

Table A1. Environmental variables from the sites where non-native turtles were found in the wild in the Republic of Korea.

Environmental Variables	Mean	Min	Max
Average monthly minimum temperature (tmin) (°C)	7.6 ± 0.1	−12.4	23.0
Average monthly maximum temperature (tmax) (°C)	17.5 ± 0.1	−1.5	32.4
Average monthly mean temperature (tmean) (°C)	12.6 ± 0.1	−6.9	26.7
Average monthly precipitation (prec) (mm)	107.2 ± 1.0	14.0	341.0
Altitude (m)	68.0 ± 3.0	0	673

Table A2. The information on the number of human population, size of region, income per capita of regions in the Republic of Korea. Number of human population and size of region were based on the data in 2018 and only income per capita is based on the data in 2017 [26]. Human density = Human population/Size of region. *: the capital.

Province	No. of Locations of Non-Native Turtles (n)	Human Population (Million)	Size of Region (km^2)	Income Per Capita (Dollars)	Human Density
Seoul *	39	9.7	606	18,456.7	1.60
Busan	25	3.4	996	15,096.9	0.34
Daegu	42	2.4	883	15,230.5	0.27
Incheon	36	2.9	1154	14,843.7	0.25
Gwangju	8	1.5	501	15,708.6	0.30
Daejeon	3	1.5	540	16,030.6	0.28
Ulsan	21	1.2	1145	18,223.5	0.10
Sejong	0	0.3	465	17,765.3	0.001
Gyeonggi	118	13.1	10,356	16,081.3	0.13
Gangwon	23	1.5	16,912	14,511.7	0.01
Chungcheong	43	3.8	16,165	29,260.0	0.02
Jeolla	50	3.6	23,500	28,304.7	0.02
Gyeongsang	211	6.0	30,834	29,414.4	0.02
Jeju	29	0.7	2050	14,787.3	0.03
Total	648	51.6	106,107	263,715.1	3.371
Mean	46	3.7	7579.1	18,836.8	0.2

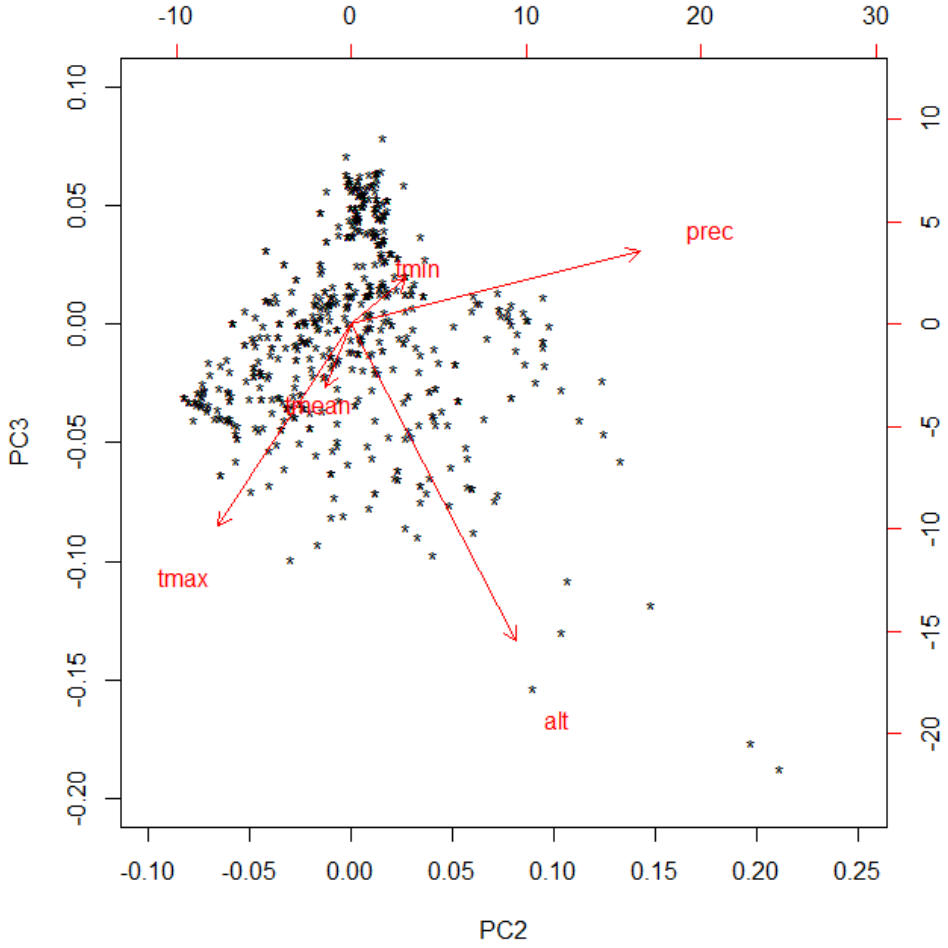

Figure A1. The PCA (principal component analysis) biplot of the second and third principal components for environmental variables associated with the distribution of non-native turtles. tmin: average monthly minimum temperature; tmax: average monthly maximum temperature; tmean: average monthly mean temperature; prec: average monthly precipitation; alt: altitude.

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