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A Morphometric Study of *Hemidactylus turcicus* Populations on the Istanbul Islands of Türkiye with Predictions of Potential Distributions

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Abstract.—**Türkiye has many islands in its territorial waters that differ geographically and climatically. Büyükada and Heybeliada are the largest islands located in the Marmara Sea and the most herpetologically diverse among the Istanbul islands. Using morphometric analysis, we compared populations of the Mediterranean House Gecko (*Hemidactylus turcicus*) in Büyükada and Heybeliada with populations previously obtained from various regions in the Turkish Republic of Northern Cyprus and Türkiye by. We analyzed differences between populations using Principal Component Analysis and Canonical Discriminant Analysis examining scalation and morphometric characters. Populations of lizards from Büyükada and Heybeliada differed significantly from populations in other regions in which the species is distributed. In addition, we discovered *H. turcicus* for the first time on Büyükada island. We applied the Ecological Niche Model to determine suitable habitats in areas accessible to *H. turcicus* through dispersal for the Last Glacial Maximum and the present. Both scenarios predicted that the coastal region of the country, including the island population, would be suitable habitat for the species. These results suggest that the species may have settled on the islands during the Last Glaciation and may have begun to separate from other populations due to the marine barrier.**

Key Words.—Büyükada; CDA; gecko; last glacial; marine barrier; PCA; Wallace

Introduction

Even though islands have various unique features such as their varying formation patterns and distance from the mainland, their isolation can provide considerable information on biogeography, ecology, and evolutionary biology of species living there (Shine 1987). Islands are the best example of geographic isolation leading to speciation (Kadmon and Pulliam 1993). Charles Darwin and Alfred Wallace made their famous discoveries using studies and observations of island populations. These island populations, which can be described as metapopulations, provide ecological and evolutionary information such as their origin, differentiation from their relatives on the mainland, and their changes in behavior associated with ecological conditions (Grant and Grant 2016; Graham et al. 2017). Therefore, the importance of island populations cannot be ignored.

Despite the importance of these studies, there has only been limited herpetological research on the Turkish Istanbul islands of Büyükada and Heybeliada (Baran 1981; Kaya and Tosunoğlu 2021). Studies on Büyükada (Istanbul province) documented the presence of the European Green Toad (*Bufotes viridis*) and two lizard species: the European Glass Lizard (*Pseudopus apodus*) and the Italian Wall lizard (*Podarcis siculus*). Surveys in Heybeliada (Istanbul province) documented three lizard species: the Mediterranean Thin-tailed Gecko (*Mediodactylus danilewskii*), the Mediterranean House Gecko (*Hemidactylus turcicus*), and *P. siculus* (Baran 1981; Kaya and Tosunoğlu 2021). The surface area of the island and species diversity are positively correlation (Molles and Sher 2022). As a consequence, species diversity on these islands has been estimated to be higher than on comparable mainland habitats.

In mainland Türkiye, seven species of the Gekkonidae family have been identified (Yaşar et al. 2021). The Baran's Leaf-toed Gecko (*Asaccus barani*) and the Large-headed Thin-toed Gecko (*Stenodactylus grandiceps*) are found only in two provinces; Şanlıurfa, Mardin, and Kilis, Gaziantep, respectively (Akman and Göçmen 2014; Yıldız et al. 2019). The Asia Minor Thin-toed Gecko (*Mediodactylus heterocercus*) is distributed from the south Mediterranean in the southeastern and eastern parts of Türkiye and the Rough Bent-toed Gecko (*Cyrtopodion scabrum*) from southeastern Türkiye. The Kotschy's Gecko (*Mediodactylus kotschyi*) is the most common gecko species in Türkiye and has recently been divided into two species, the Bulgarian Bent-toed Gecko (*Mediodactylus danilewski*) and the Mediterranean Thin-toed Gecko (*M. orientalis*; Kotsakiozi et al. 2018). Of these gecko species, *H. turcicus* is found most abundantly on the coastline of the country and on islands, which makes it a good species to study the island effect on gekkonid lizards.

Türkiye has a diverse herpetofauna due to its biogeographic variation and topography (Kurnaz 2020). Although Türkiye is not as rich in *Hemidactylus* species as some other African and Asian countries, *Hemidactylus* is a highly diverse lizard genus with around 190 identified species (http://www.reptile-database.org/ [Accessed 28 November 2022]). More than 49% of the species belonging to this genus have been described since 2000. *Hemidactylus* has a higher species diversity than other gecko taxa (Bauer et al. 2010). Among these species, *H. turcicus*, the Indo-Pacific Gecko (*H. garnotii*), the Common House Gecko (*H. frenatus*), and the Tropical House Gecko (*H. mabouia*) have the widest distributions (Bauer et al. 2010; Weterings and Vetter 2018). Aside from natural habitats of forest bushes and stony areas, species of *Hemidactylus* also inhabit ruins of structures and domestic buildings (Vogrin and Miklic 2005; Weterings and Vetter 2018). Because they inhabit common areas with humans, they also can be found occasionally in boats, ships, trucks, and other transport vehicles carrying cargo. Thus, it is thought that their potential to be transported to remote areas by marine or land vehicles is very high (Heinsohn 2003; Norval et al. 2012; Weterings and Vetter 2018). Some species of this highly adaptable genus regularly move between coastal areas and islands (Heinsohn 2003).

Hemidactylus turcicus is the only identified *Hemidactylus* that is widely distributed in the Mediterranean, Aegean, Black Sea, and the Marmara coast and southeastern Anatolia region of Türkiye. The identified populations of the species were defined as a nominate subspecies (Başoğlu and Baran 1977; Baran 1981; Baran and Gruber 1982; Baran and Atatür 1998; Bülbül et al. 2020). Because these lizards occur in human habitations, it is not surprising that they are especially found in areas with high levels of human movement, such as islands. In Türkiye, *H. turcicus* is reported from most of the islands in the Aegean region located close to the mainland (Baran 1981).

We aimed to determine if *H. turcicus* populations on Büyükada and Heybeliada differ significantly in scalation and morphology from the populations of the mainland (Istanbul), Mediterranean, Eastern, Aegean, and Cyprus populations. Because the islands are surrounded by formidable barriers such as the Marmara Sea and are also located very close to the mainland, populations may have differentiated morphologically. Ecological niche models reveal past and future population trends by evaluating population distribution and environmental conditions that allow a species to maintain distribution (Sillero et al. 2021). We applied Ecological Niche Modeling on suitable habitats for the past (Last Glacial Maximum; 21,000 y ago) and present (1980–2010) time periods to determine if there were suitable habitat areas on islands for *H. turcicus* in the past and if this area provided suitable conditions for species distribution or if the species most likely reached the area through human transportation in recent times. We provide information regarding the importance of the island populations of *H. turcicus* and provide a basis for further research.

Materials and Methods

Study area.—Büyükada, which is a part of Istanbul providence of Türkiye, is located on the northeast of the Marmara Sea and the nearest mainland is 4.1 km away (Özyiğit 2003; Fig. 1). With an area of approximately 5.4 km², it is the largest and most densely populated of the Istanbul islands (Özyiğit 2003). Heybeliada is the second largest island after Büyükada. On both islands, residential areas are concentrated in the northern part of the island and the part facing the mainland. In the southern part, there are green spaces, picnic areas, beaches, and protected areas. Geological formations of the islands are from sometime during the Miocene period (23.03–5.33 Mya) by the rise and fall of the Trace-Kocaeli peneplain (Garipağaoğlu 1999). Climatically, the area has a Mediterranean climate and not the Marmara climate prevailing in the rest of the geographic area where it is located (Günal 1998). Widespread and dominant Red Pine (*Pinus brutia*) forests and Maquis are the dominant vegetation on the islands (Günal 1998). The average annual temperature of the island is around 14° C, in the summer the temperature is above 25° C, the humidity is high, between 73–77%, and the annual precipitation averages about 823 mm (Akyıldırım and Görür 2021).

Sampling.—We conducted field trips to Büyükada and Heybeliada islands from March to November in 2021 and 2022, when the weather was best for gecko activity. These months are the active periods of *H. turcicus*. To ensure effective sampling, we worked with a team of at least four people. We conducted field trips throughout the islands to areas such as stony areas, forests, roadsides, and ruined structures. Due to the large area of the island, we used a randomized walk design during daylight hours to sample for lizards. We used a handheld GPS device to measure latitude, longitude, and elevation (m), and we photographed the vegetation and recorded the name of the location where

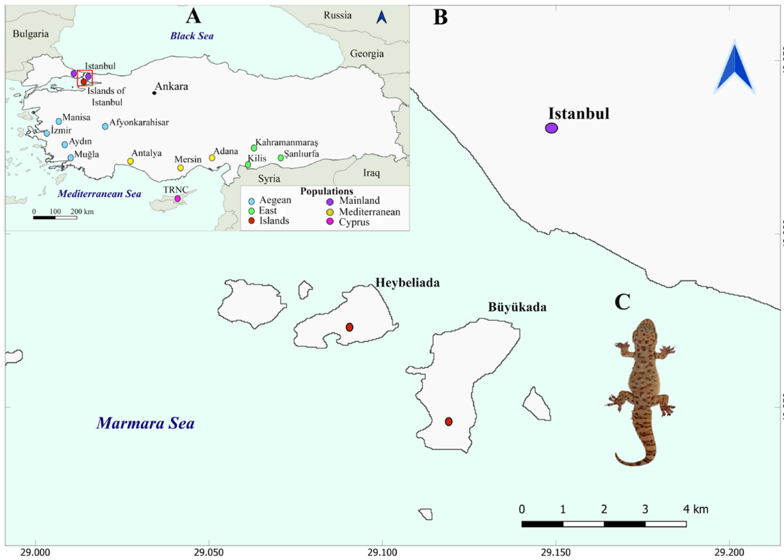

Figure 1. Distribution of populations of the Mediterranean House Gecko (*Hemidactylus turcicus*) from island and mainland habitats used in morphometric analysis in (A) Türkiye and the Turkish Republic of Northern Cyprus and (B) populations of Büyükada and Heybeliada of the Islands of Istanbul. (C) Dorsal view of a male individual from the islands population.

we captured specimens. We collected 18 *H. turcicus* from Büyükada and 11 from Heybeliada. In accordance with the Animal Experiments Local Ethics Committee of Istanbul University, we injected sodium pentobarbital intraperitoneally to euthanize the lizards. In addition to the island samples, we obtained data for 83 *H. turcicus*, which were collected in the region of mainland Istanbul, the Aegean region (Afyon, Aydın, Izmir, Manisa, Muğla), the Mediterranean region (Antalya, Mersin), the Eastern region (Kahramanmaraş, Kilis, and Şanlıurfa), and the Turkish Republic of Northern Cyprus populations. The museum samples belonged to the zoological collections at Adıyaman University (ZMADYU), Türkiye. We mapped the distributions of the samples using the QGIS 3.26.0-Buenos Aires map program (https://www.qgis.org/en/site/forusers/download.html [Accessed 12 July 2022]; Fig. 1).

Morphometric measurements.—We noted sex and took measurements of scalation and morphometric characters for every specimen collected from the islands. We did not include specimens without tails or with regenerated tails for this study. We measured scale characters and counts as follows using a SZ61 binocular microscope (Olympus Corporation, Shinjuku, Tokyo, Japan): (1) UL (number of upper labials); (2) LL (number of lowest labials); (3) IO (interorbitals); (4) SLNAO (scales between lower nasal and anterior border of orbit); (5) G (gulars); (6) LDTR (counted across mid abdomen); (7) LVR (longitudinal ventral scale rows); (8) LUFS (lamellae under first toe); (9) LUFT (lamellae under fourth toe); and (10) PRP (preanal pores). We used a 0.01 mm digital caliper to measure these other characters: (11) SVL (snout-vent length); (12) TL (tail length); (13) HL (head length); (14) HW (head width); (15) BW (body width); (16) HD (head depth); (17) HOD (horizontal orbit diameter); (18) EOD (horizontal ear diameter); (19) DAOST (distance between anterior edge of orbit and snout tip); (20) OEL (distance between posterior edge of orbit and anterior edge of ear). We determined which characters to measure based on the study by Yıldız et al. (2007). We also compared populations using previously measured data from them.

Statistical analysis.—We compared the population of Büyükada and Heybeliada with populations belonging to the mainland (Istanbul), Aegean region (Afyon, Aydın, Izmir, Manisa, Muğla), Mediterranean region (Antalya, Mersin), Eastern region (Kahramanmaraş, Kilis, and Şanlıurfa), and the Turkish Republic of Northern Cyprus populations. We used six populations for statistical analysis that can be differentiated by considering the barriers between populations according to the zoogeography of Türkiye. We classified the Istanbul specimens (including the Marmara region), which are the nearest to the islands, as mainland populations. For statistical analyses, we used 10 scale characters. For body measurements, we used the PERCRA index (percentage of SVL; each metric character/SVL × 100; Werner 1971) to eliminate errors that may arise from the size difference between specimens. In total, we used 19 characters as data for morphometric analysis. We calculated the minimum (Min), mean, maximum (Max), and standard deviation (SD) values of the characters according to the defined populations. We used the Shapiro-Wilk Test to determine if each character was normally distributed at the level of a taxon. We rejected the null hypothesis that characters have a normally distributed distribution if the calculated *P*-value for a certain character was < 0.05. We detected an outlier value between populations and a critical morphological value that distinguished between them. We used Principal Component Analysis (PCA) and Canonical Discriminant Analysis (CDA) to display morphological characters between populations. We made PCA and CDA analyses with R version 4.2.1. software (R Core Team 2022) and performed these analyses using the statistical package MorphoTools2 (Šlenker et al. 2022). We used Analysis of Variance (ANOVA) to determine if normally distributed characters differed among groups. To determine whether sexual dimorphism and snout-vent length were significantly different among populations, we used Multivariate Analysis of Variance (MANOVA). We performed ANOVA and MANOVA using the dplyr package implemented in R version 4.2.1. software (R Core Team 2022).

Ecological Niche Modeling.—We obtained the presence data (234 records) for *H. turcicus* from field surveys (three records), 27 literature records from the Aegean region (Baran 1981; Yıldız et al. 2007; Özcan and Üzüm 2014), Black Sea region (Bülbül et al. 2020), Central Anatolia (Afsar and Tok 2011; Cihan and Tok 2014), Eastern region (Uğurtaş et al. 2007; Yıldız et al. 2007), Marmara region (Baran 1981; Hür et al. 2008; Yıldız et al. 2007; Özgül et al. 2022), and Mediterranean region (Yıldız et al. 2007; Kucharzewski 2015; Altunışık 2017), and 204 records from three databases (http://www.turkherptil.org/ [Accessed 10 December 2022]; https://www.gbif.org/ [Accessed 14 December 2022] https://observation.org/ [Accessed 17 December 2022]). Presence data range from the 1980s to 2022. We performed the Ecological Niche Modeling using Wallace (v1.1.3; https://wallaceecomod.github.io/), which is an open-source graphical user interface (GUI) application that has access to R-scripted modern workflows (Kass et al. 2018). We spatially filtered the presence records by reducing multiple records within 20 km distances into single record, resulting in 110 presence records. We downloaded bioclimatic data from Chelsea V.2.1. database (https://chelsa-climate.org/) with a spatial resolution of 2.5 arc-minutes from the Paleoclimate Model Intercomparison Project Phase 3 (PMIP3) data for past (Last Glacial Maximum; Karger et al. 2021) and present (Karger et al. 2017). We used nine bioclimatic variables (Bio1, Bio2, Bio3, Bio4, Bio6, Bio7, Bio12, gdd10, gsl; Supplemental Information Table 1) that were thought to affect the distribution of the species. For selecting the background extent, we applied a 5-degree bounding box, and we sampled 10,000 background points. We partitioned presence data using a spatial partitioning (Block, k = 4) that divided records into four equal bins based on latitudinal and longitudinal lines (Supplemental Information Fig. 1). We tested the L (linear), LQ (linear and quadratic), H (hinge), LQH (linear, quadratic, and hinge), and LQHP (linear, quadratic, hinge, and product) models for each candidate model with five values of regularization multiplier (0.5 to 9.5 in increments of 1). We selected the model with the highest level of overfitting and discrimination among candidate models. We projected the final model onto past and present conditions of the sampling area, and we mapped each scenario by the QGIS version 3.24.3 software (https://www.qgis.org/en/site/forusers/download.html). In the bioclimatic suitability maps, classifications ranged from 0 (low suitability) to 1 (high suitability).

Results

We analyzed 112 specimens morphometrically using 19 characters from Türkiye and the Turkish Republic of Northern Cyprus (TRNC). We used scale and morphometric data of 29 adult specimens from Büyükada and Heybeliada (18 females, 11 males), 10 specimens from the Aegean population, 11 specimens from the Eastern population, four specimens from the mainland (Istanbul), 35 specimens from the Cyprus population, and 23 specimens from the Mediterranean population. The dorsal parts of the island lizards were light brown with dark brown thick spots. The ventral part was light-colored and yellowish white (Table 1).

The characters UL, LL, IO, LDTR, LUFS, LUFT, PRP, TL/SVL×100, HD/SVL×100, and EOD/SVL×100 were not normally distributed for island populations (all $P < 0.05$) and were not used in the analyses. PCA and CDA analyses demonstrated that Büyükada and Heybeliada populations are separated as a distinct cluster from the other populations where the species is distributed in Türkiye (Fig. 2). The mainland population (Istanbul) was closest to the island population. The other populations identified, the Mediterranean, the Aegean, the Eastern and the Cyprus populations, clustered quite close to each other.

Analyzed separately, SLNAO ($F_{5,106} = 4.73$, $P < 0.001$), G ($F_{5,106} = 50.14$, $P < 0.001$), LVR ($F_{5,106} = 5.99$, $P < 0.001$), HW/SVL×100 ($F_{5,106} = 3.59$, $P < 0.001$), HL/SVL×100 ($F_{5,106} = 10.84$, $P < 0.001$), BW/SVL×100 ($F_{5,106} = 8.83$, $P < 0.001$), HOD/SVL×100 ($F_{5,106} = 7.30$, $P < 0.001$), DAOST/SVL×100 ($F_{5,106} = 22.64$, $P < 0.001$), and OEL/SVL×100 ($F_{5,106} = 5.58$, $P < 0.001$) differed significantly among populations of the islands (Fig. 3). There was an overall significant difference among populations ($F_{10,212} = 3.04$, $P < 0.001$). The morphology of males and females did not differ significantly ($F_{5,106} =1.28$, $P = 0.277$), but snout-vent length irrespective of

Table 1. The number of individuals (n) in populations of the Mediterranean House Gecko (*Hemidactylus turcicus*) from island and mainland habitats that were measured morphologically showing the mean ± standard deviation and minimum and maximum values in parentheses. Characters measured were UL = number of upper labials, LL = number of lowest labials, IO = interorbitals, SLNAO = scales between lower nasal and anterior border of orbit, G = gulars, LDTR = counted across mid abdomen, LVR = longitudinal ventral scale rows, LUFS = lamellae under first toe, LUFT = lamellae under fourth toe, PRP = preanal pores, SVL = snout-vent length, TL = tail length, HL = head length, HW = head width, BW = body width, HD = head depth, HOD = horizontal orbit diameter, EOD = horizontal ear diameter, DAOST = distance between anterior edge of orbit and snout tip, and OEL = distance between posterior edge of orbit and anterior edge of ear.

Character	Aegean (n = 10)	East (n = 11)	Islands (n = 29)	Mainland (n = 4)	Cyprus (n = 35)	Mediterranean (n = 23)
UL	8 ± 0.67 (7–9)	8 ± 0.77 (7–9)	8.41 ± 0.73 (7–10)	8 ± 0.82 (7–9)	7.86 ± 0.55 (7–9)	8.22 ± 0.42 (8–9)
LL	6.3 ± 0.48 (6–7)	6.55 ± 0.52 (6–7)	7.03 ± 0.33 (6–8)	6.5 ± 0.58 (6–7)	6.23 ± 0.59 (5–7)	6.78 ± 0.52 (6–8)
IO	30.2 ± 2.52 (25–33)	28.64 ± 4.32 (21–37)	29.55 ± 1.35 (26–32)	29.75 ± 2.22 (27–32)	29.23 ± 2.82 (24–34)	30.91 ± 3.06 (25–37)
SLNAO	13.7 ± 1.06 (12–16)	13.64 ± 1.361 (11–15)	13.89 ± 0.86 (11–15)	13.25 ± 0.96 (12–14)	13.66 ± 0.84 (11–16)	15.35 ± 2.27 (11–19)
G	51.1 ± 2.23 (47–54)	50 ± 4.40 (44–58)	65.34 ± 3.37 (58–73)	61.5 ± 4.65 (56–67)	50.86 ± 4.03 (44–58)	52.78 ± 4.52 (44–60)
LDTR	13.9 ± 0.57 (13–15)	13.64 ± 0.80 (12–14)	14 ± 0.38 (13–15)	13.25 ± 0.96 (12–14)	13.71 ± 0.75 (12–15)	13.65 ± 1.15 (12–16)
LVR	40.5 ± 2.42 (37–44)	40.09 ± 2.77 (35–46)	37.66 ± 1.45 (35–41)	38.25 ± 1.26 (37–40)	39.69 ± 2.99 (33–45)	41.17 ± 2.53 (36–46)
LUFS	7.3 ± 0.82 (6–9)	7.45 ± 0.69 (7–9)	10.03 ± 0.57 (9–11)	8.25 ± 2.06 (6–10)	6.89 ± 0.40 (6–8)	7.04 ± 0.21 (7–8)
LUFT	8.2 ± 0.63 (7–9)	8.73 ± 0.65 (8–10)	8.07 ± 0.37 (7–9)	8 ± 0.82 (7–9)	8.17 ± 0.51 (7–10)	8.17 ± 0.39 (8–9)
PRP	2.2 ± 3.61 (0–9)	3.27 ± 3.82 (0–8)	2.62 ± 3.20 (0–8)	1.75 ± 3.5 (0–7)	3.83 ± 3.29 (0–8)	3 ± 3.22 (0–7)
SVL	47 ± 5.79 (39–54)	39.55 ± 11.38 (21–54)	50.25 ± 6.31 (36.29–58.5)	42.66 ± 11.22 (28–55.08)	42.89 ± 9.18 (21–53)	43.52 ± 8.11 (29–54)
TL	48.1 ± 5.04 (40–57)	39.90 ± 10.91 (23–55)	51.70 ± 9.82 (20.15–66.74)	49.67 ± 9.92 (37–60.63)	44.57 ± 10.28 (22–60)	43.96 ± 8.97 (28–63)
HL	12.67 ± 1.43 (10–14.63)	11.09 ± 2.55 (7.14–14.25)	12.91 ± 1.64 (9.75–15.17)	11.27 ± 1.72 (9.13–13.34)	12.32 ± 2.25 (7.49–15.87)	12.01 ± 2.21 (8.18–14.8)
HW	9.53 ± 1.14 (7.58–10.97)	7.83 ± 2.09 (4.92–10.88)	10.36 ± 1.27 (7.58–12.3)	9.28 ± 2.65 (6.19–12.33)	8.44 ± 1.75 (4.86–10.93)	8.54 ± 1.52 (5.52–11.01)
BW	10.62 ± 1.86 (8.16–13.92)	8.49 ± 3.14 (3.89–13.04)	11.78 ± 2.11 (7.3–15.41)	9.33 ± 3.03 (5.9–11.91)	8.60 ± 2.34 (3.86–12.43)	9.36 ± 1.91 (5.52–12.1)
HD	6.08 ± 1.16 (4.48–8.01)	4.96 ± 1.13 (3.28–6.54)	5.40 ± 0.81 (3.92–7.64)	6.04 ± 1.58 (4.07–7.62)	5.32 ± 1.17 (2.74–7.11)	5.24 ± 0.97 (3.25–6.62)
HOD	2.81 ± 0.27 (2.38–3.16)	2.39 ± 0.45 (1.8–3.03)	2.79 ± 0.33 (2.01–3.39)	2.86 ± 0.47 (2.42–3.49)	2.71 ± 0.44 (1.63–3.47)	2.53 ± 0.42 (1.83–3.39)
EOD	0.44 ± 0.17 (0.12–0.69)	0.39 ± 0.09 (0.29–0.55)	1.14 ± 0.19 (0.77–1.72)	0.80 ± 0.35 (0.44–1.23)	0.49 ± 0.14 (0.26–0.75)	0.48 ± 0.18 (0.2–1.03)
DAOST	4.27 ± 0.50 (3.47–4.98)	3.68 ± 0.85 (2.21–4.71)	4.14 ± 0.55 (2.91–5.09)	3.79 ± 0.88 (2.53–4.55)	4.13 ± 0.81 (2.33–5.27)	3.81 ± 0.75 (2.35–5.02)
OEL	4.36 ± 0.51 (3.65–5.07)	3.63 ± 0.86 (2.2–5)	4.44 ± 0.64 (3.1–5.64	3.99 ± 1.00 (2.84–5.27)	3.98 ± 0.83 (2.22–5.11)	3.74 ± 0.70 (2.5–4.83)

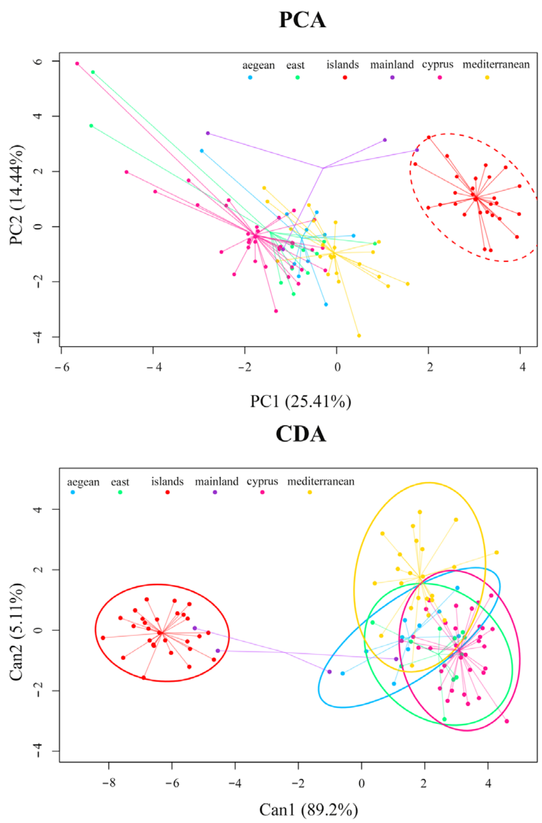

Figure 2. Principal Component Analysis (PCA) and Canonical Discriminant Analysis (CDA) of Islands, Mainland (Istanbul), Mediterranean, Aegean, Eastern, and Cyprus populations of the Mediterranean House Gecko (*Hemidactylus turcicus*).

sex was significantly different among populations ($F_{5,106}$ = 5.69, $P < 0.001$).

Ecological niche modeling.—The modeling process created 50 candidate models. The final model used variables Bio1, Bio2, Bio3, Bio4, Bio6, Bio7, Bio12, gdd10, and gsl feature classes of linear, quadratic, and hinge and a regularization multiplier of 0.5. This model used all of nine input variables (Supplemental Information Table 2). We classified the performance of final model as excellent (0.9–1.0) with the value of AUC = 0.903 (Supplemental Information Table 3). The current habitat suitable areas of *H. turcicus* cover mostly coastal areas of Türkiye (Fig. 4). Comparing the current habitats, suitable areas cover similar areas under the Last Glacial Maximum conditions except for the European part of Marmara and the coastal areas of the Black Sea region (Fig. 4).

Discussion

Hemidactylus turcicus is a widely distributed species in Türkiye, found mainly in coastal areas (Baran 1981; Baran and Atatür 1998; Bülbül et al. 2020; Yıldız et al. 2007). The species, which has also been recorded from many islands in the Aegean and Marmara regions, has been reported only from Heybeliada and Kınalıda from the Istanbul islands (Baran 1981; Kaya and Tosunoğlu 2021). We found for the first time a population belonging to this species from Büyükada, the largest of the Istanbul islands. It is plausible that the recorded population is concentrated in the southwestern part of Büyükada where brush vegetation is predominant. Based on our observations, this region has seen relatively less human activity than other parts of the island. The Heybeliada population was reported previously (Kaya and Tosunoğlu 2021) but we morphometrically analyzed the Büyükada population for the first time with a large number of specimens in this study. We analyzed island populations using morphometric characters from the Mediterranean, mainland (Istanbul), Eastern, Aegean, and Cyprus populations.

Our analysis indicated that the island populations differed significantly from other identified populations. We observed that this population was different from the *H. turcicus turcicus* line described for Türkiye. In the specimens of the islands population, the Gulare (G) number is high with an average of 65, while this number is 61 in the nearest mainland. In other populations, this number averages between 50 and 52. The number of longitudinal ventral scale rows (LVR) was higher in other populations and lower in the island population, with an average of 37. Also, the number of LVRs of the mainland specimens was closer to the island populations. Lizards from the Büyükada and Heybeliada populations were larger than lizards from other populations, with an average SVL of 50 mm in island populations compared to 39–47 mm. According to previous studies, the tendency to gigantism among small-bodied reptiles is stronger on isolated, small islands, with stronger effects of area than isolation (Benítez-López et al. 2021). We found that the characters HL, HW, BW EOD, and OEL were larger in island lizards than other populations on the mainland. Additionally, modified characters (/SVL×100) HW, HL, BW, HOD, DAOST, and OEL were also important in the distinguishing island from mainland lizards.

The first records of the *Hemidactylus turcicus* species in Türkiye included the Mediterranean and Aegean coastal regions (Başoğlu and Baran 1977). Analyses using morphometric measurement data such as age and SVL data on the Mediterranean and Aegean populations showed that there was a distinction between the two populations (Altunışık 2017). It was believed that this situation was due to the effects of climatic differences on the species in different geographical regions (Altunışık 2017). In their studies on the Aegean and Marmara Islands, Baran (1981) recorded the species from 46 different islands, mostly Aegean Islands. Baran (1981) stated that the *H.*

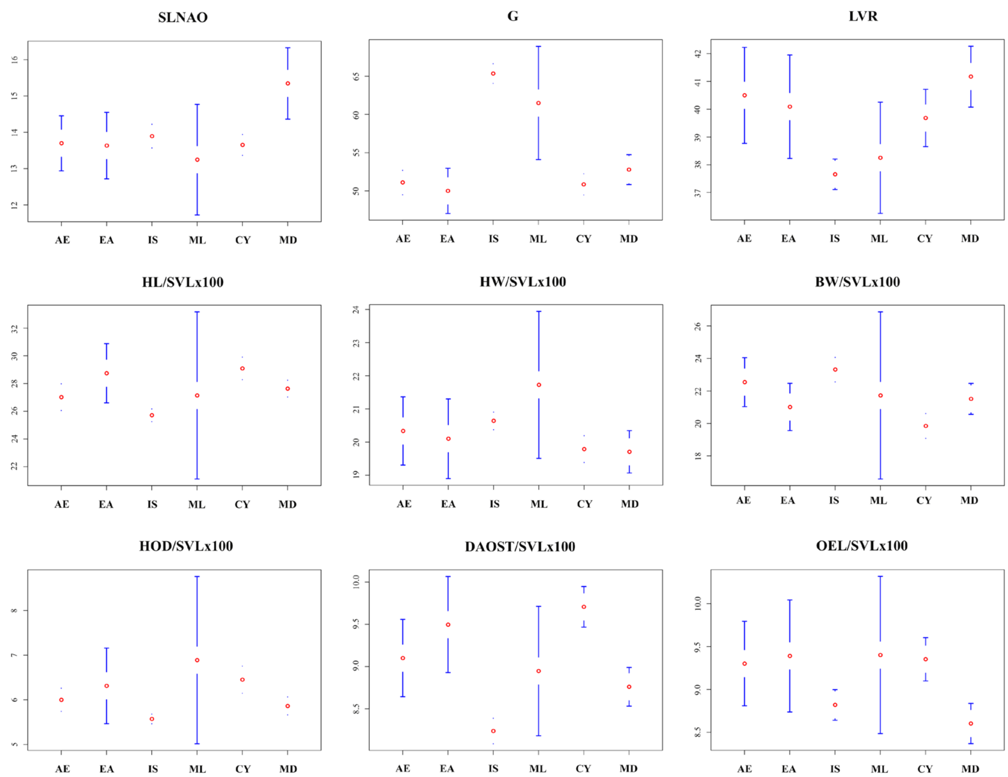

Figure 3. Plots of significant distinguishing characters among populations (AE: Aegean, EA: Eastern, IS: Islands, ML: Mainland, CY: Cyprus, MD: Mediterranean): scales between lower nasal and anterior border of orbit (SLNAO), gulare (G), longitudinal ventral scale rows (LVR), head width / snout-vent length × 100 (HW/SVL × 100), head length / snout-vent length × 100 (HL/SVL × 100), body width/ snout-vent length × 100 (BW/SVL × 100), horizontal orbit diameter / snout-vent length × 100 (HOD/SVL × 100), distance between anterior edge of orbit and snout tip / snout-vent length × 100 (DAOST/SVL × 100), and distance between the posterior edge of orbit and anterior edge of ear / snout-vent length × 100 (OEL/SVL × 100). Mean values are shown with red circles, and 0.95 confidence intervals are represented with vertical bars.

turcicus collected from the islands in the Aegean and Marmara regions did not differ from the population in Anatolia in terms of morphological features. In the subsequent studies, the distribution area of the species was extended to Şanlıurfa in the east (Yıldız et al. 2007). Statistical analyses made with Kilis specimens from the eastern population showed a significant difference in the morphometric characters from the Aegean and Mediterranean populations (Yıldız et al. 2007).

We observed that the mean body length of individuals belonging to the Kahramanmaraş, Kilis, and Şanlıurfa populations, which are the eastern population specimens used in the morphometric analysis, was smaller than the populations in the other regions. The first locations of the species on the Black Sea coast were recorded by Baran and Gruber (1982). Morphometric analysis made with lizards from Zonguldak, Sinop, and Trabzon along the Black Sea coasts showed that populations in

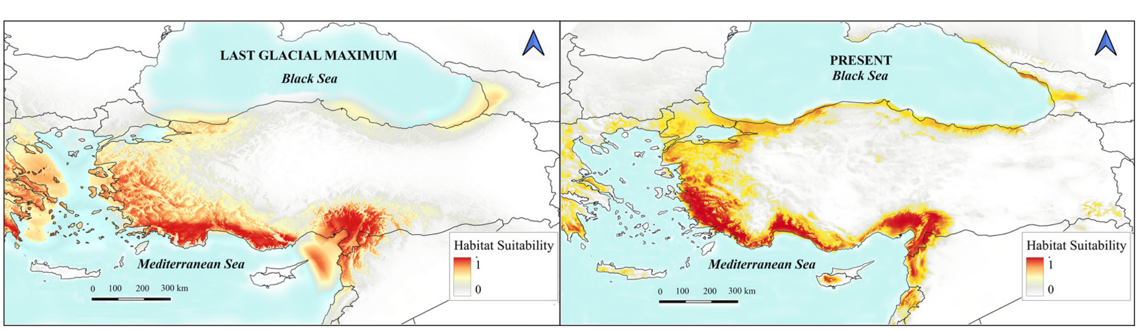

Figure 4. Habitat suitability prediction for populations of the Mediterranean House Gecko (*Hemidactylus turcicus*) under past (Last Glacial Maximum; 21,000 y ago) and present (1981–2022) conditions.

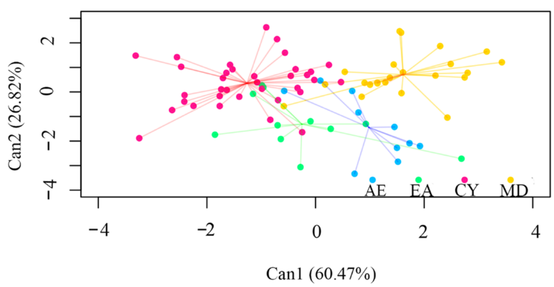

Figure 5. Canonical Discriminant Analysis (CDA) of Mediterranean (MD), Eastern (EA), Aegean (AE) and Cyprus (CY) populations of the Mediterranean House Gecko (*Hemidactylus turcicus*).

this region are not morphologically different from the populations in the other regions (Bülbül et al. 2020), but a comprehensive morphometric analysis was not performed due to insufficient sampling. The climatic and geographical structure of the Black Sea region, which is the region with the highest annual precipitation, is quite different from other regions (Sensoy et al. 2008). Therefore, a comprehensive study of the population distributed in the Black Sea region with more specimens will give more meaningful results about the population in this region.

The climatic and geographical differentiation in the regions where *H. turcicus* is distributed in Türkiye also causes differences in elevation, soil, and vegetation (Avcı 2000; Bilgin 2011; Duran 2013). These differences can cause high species diversity, divergence, and differentiation of populations (Atalay 2006; Şekercioğlu et al. 2011). In addition to the geographical differences, due to its aquatic or terrestrial barriers (Dubey et al. 2007; Kocataş 2008), Türkiye has a zoogeography in which lizard species especially show speciation or subspeciation (Ahmadzadeh et al. 2013; Kapli et al. 2013; Kurnaz et al. 2019; Kornilios et al. 2020; Kafimola et al. 2023). Aside from this, it has been shown that the experimental introduction of a small propagule of lizards into a novel habitat resulted in large variations in external morphology with high phenotypic divergence rates within a few generations (Herrel et al. 2008).

While performing the morphometric analyses, we performed a separate analysis using Mediterranean, Eastern, Aegean, and Cyprus populations without the island and mainland populations to better visualize the differences, if any, between these four populations. These populations are clustered in separate centers of distribution (Fig. 5). According to the ecological niche model, the habitat areas suitable for the species from the Last Glacial Maximum to the present were estimated as the coastal regions of the country. We found that suitable habitat areas are still concentrated in the coastal areas. There are many records of *H. turcicus* from the literature in the coastal part of the Mediterranean climate type where the average temperature is high. In addition, we have found that suitable habitat areas for the species have increased especially on the shores of the Black Sea and Marmara regions (unpubl. data). On the other hand, the suitable habitat areas from the inner parts of the country to the east are very low in elevation. There are very few locality records from these areas. This suggests that the species may have been transported here by vehicles. As one of the most effective colonizers, this species is frequently constrained to areas of anthropogenic origin, and its ability to spread further is limited by climate conditions (Urošević et al. 2023). We conclude that the coastal parts of the Anatolian side, the location of present-day Istanbul Islands during the last glacial period, contain suitable habitats for the species. This supports the view that the species may have settled on the islands beforehand.

Rato et al. (2011) indicated two lineages in a phylogenetic study conducted with European, Anatolian, and African samples along the Mediterranean coasts. One of these lineages is the population in the northern Mediterranean region. It was emphasized that the population in Anatolia could be the origin of both lineages (Rato et al. 2011). We show that the northern lineage significantly differs from the lineage in the south of Türkiye. To better demonstrate this distinction, which is shown by morphometric data, a more comprehensive genetic and morphological study should be carried out, especially including the Aegean islands and Black Sea populations. Results from such a study will provide the opportunity to make better interpretations about the migrations between the lineages in Europe and Africa. In conclusion, we expect that this study will serve as a basis for future research regarding the morphological changes of populations of *H. turcicus*, particularly those on islands, and will play an important role in conservation studies.

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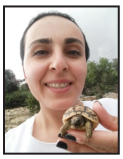

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