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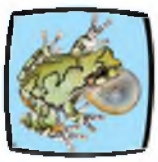

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Biodiversity of the Herpetofauna of the Muyunkum Desert, Kazakhstan

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The Muyunkum Desert is situated in southern Kazakhstan. This sandy desert, with an area of 37,500 km^2, stretches from southeast to northwest for about 500 km. It is located in the middle of the North Turanian deserts. From the south and west, it is bounded by the Karatau Ridge, from the east by the Chu-Iliysky Mountains, and from the north by the Betpak-Dala Desert. Because of its location, this desert is the limit of northward distribution for a number of reptile species and is habitat for isolated populations of the psammophilous species.

The first references to the herpetofauna of the Muyunkum Desert date from the second half of the last century. Paraskiv (1956) listed a total of 16 species for the Muyunkum Desert and surrounding areas. However, most of the findings were mentioned without precise geographical attribution. In subsequent years, research studies have been fragmentary. In 1967, censuses of *Eremias grammica* (Lichtenstein, 1823), *Eremias velox* (Pallas, 1771), and *Phrynocephalus mystaceus* (Pallas, 1776) were conducted on the southern periphery of the Muyunkum Desert (Vtorov and Pereshkolnik 1970). In 1978, data on new findings and abundance of five reptile species were obtained (Brushko 1995; Kubykin and Brushko 1998; Brushko and Kubykin 2000). In the late 1980s, *Eremias lineolata* (Nikolsky, 1896) was recorded for the first time on the eastern edge of the desert; and there were also findings of *Hemorrhois ravergieri* (Menetries, 1832) on the northern edge (Golubev 1990). In 1994, studies of *Teratoscincus scincus* (Schlegel, 1858) in the southeastern periphery of the desert were reported (Borkin et al. 2007). By the same authors, 10 reptile species were also recorded there. Two inventories of *Testudo horsfieldii* Gray, 1844 on the southern edge of the desert were conducted in 2003 and 2005 (Bondarenko et al. 2008). The localities of some species of lizards and snakes are given in the survey monographs by Sindaco and colleagues (Sindaco and Eremchenko 2008; Sindaco et al. 2013); however, due to the small scale of the maps used, it is difficult to estimate the distribution of species in this region. Thus, most of the available information on reptiles is fragmentary and refers to areas peripheral to the Muyunkum Desert. There is no complete list of reptiles of this area and the data on their distribution and population density are insufficient. In this regard, the aim of this work is to compile a list of the herpetofauna of the Muyunkum Desert and also to clarify the distribution and relative abundance of the reptiles.

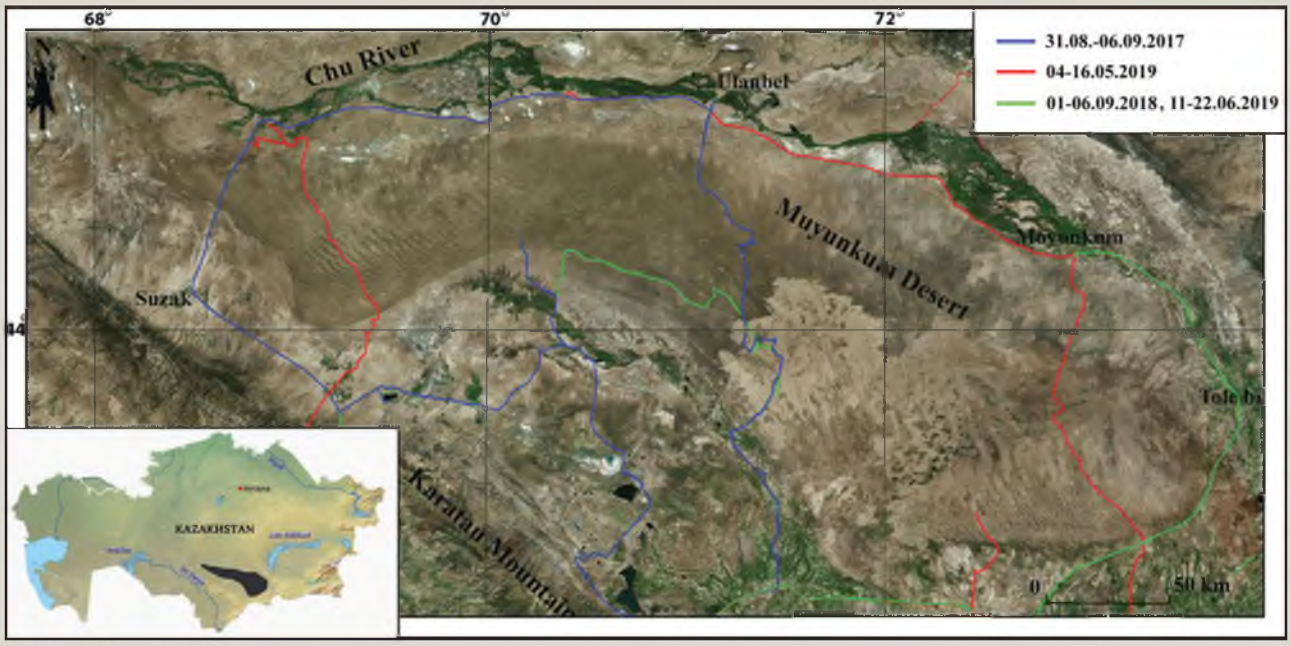

FIG. 1. Study routes.

MATERIALS AND METHODS

Study Area.—The Muyunkum Desert consists of hilly-ridged sands of moraine and river sediments from the Chu River. The higher southern part with sand dunes, up to 640 m in height, decreases gradually in the north and northwest to 110–130 m. The northern part of the desert adjoining the Chu Valley consists mainly of a hilly-ridged plain 15–30 km wide. Numerous salt marshes and pans are located closer to the Chu River. The river dries up in the summer. In the river valley, there are thickets of willow (*Salix* sp.), oleaster (*Elaeagnus* sp.), and other vegetation typical for riparian zones. In the western part of the desert, fixed dunes prevail. On the dry aligned valleys, White Earth Wormwood (*Artemisia terrae albae*), Erkek (*Agropyron* sp.), and Black Saxaul (*Haloxylon aphyllum*) dominate on dry flat valleys and the areas between dunes, and are covered with dry lichen. The central part of the desert is characterized by high sand ridges (50–70 m high). Vegetation on slopes is represented by different species of Calligonum (*Calligonum* spp.), Sand Acacia (*Ammodendron* sp.), White Saxaul (*Haloxylon persicum*), and Mammoth Wild Rye (*Leymus racemosus*). In the southeastern part of the desert there are numerous places of groundwater discharge and lake-marshy lowlands with bordering reed beds and sedge meadows. The northeastern part of the Muyunkum is covered with the saxaul trees (Bizhanova 1998; Dzhanaliyeva 1998; Bedareva 2009).

Within the Muyunkum Desert area, there is the Umbet state hunting farm, the Andysay state wildlife area, as well as two gas-condensate fields and a uranium mine.

Timing and Distance of Research Trips.—Expeditions took place during 2017–2019 (31 August 31–6 September 2017, 1–6 September 2018, 4–16 May 2019, and 11–22 June 2019) (Fig. 1). Field work was undertaken during the periods of maximum reptile activity (spring, summer and autumn months). The total length of the expedition routes was > 2000 km.

Methods.—To identify reptiles and assess their numbers, walking routes (line-transect) were used. For obligate psammophiles of *P. mystaceus*, *T. scincus*, *E. grammica* occupying only limited sections of bare sand, counts were conducted by the trial-areas method. The width of walking routes was 3–5 m, depending on the vegetation density. The faunistic records were usually supplemented with photographs of specimens and habitats. Coordinates of all localities were recorded using GPS. The results are given in terms of descriptive statistics: minimum (min) and maximum (max) values, average (M), and average error (m). The calculations were performed in Statistica 10.0. During preparation of maps, we used our own data, literature data, and data from the collections of the Institute of Zoology of the Republic of Kazakhstan (IZK), the Zoological Museum of Moscow State University (ZMMU), the Zoological Institute of the Russian Academy of Sciences (ZISP) (Appendix 1), the National Museum of Natural History, National Academy of Sciences of Ukraine (NMNH) (Shcherbak et al. 1997), and the Kyrgyz Biological-Soil Institute (Eremchenko et al. 1992). The maps are based on Bing Maps satellite imagery in the SAS Planet program. A well-known and informative method of the rank/abundance plot (or Whittaker plot) was used to display the distribution of species abundance (Magurran 2004).

Taxonomy and nomenclature of reptiles was adopted from the latest systematic lists of Kazakhstan (Dujsebayeva 2013) and Reptile Database (Uetz et al. 2019). The populations of toads in Muyunkum require taxonomic clarification. According to the latest revision, *Bufotes perrini* Mazepa et al., 2019 inhabit areas north of Karatau (Dufresnes et al. 2019). Until special studies are implemented, we will consider that this species inhabits Muyunkum Desert. Zoogeographical affiliations were identified according to the classification of Rustamov (1981) and Vigna Taglianti et al. (1999).

RESULTS

Species composition.—We found one species of amphibian and 14 species of reptiles. Two species (*Natrix tessellata* [Laurenti, 1768] and *Pseudopus apodus* [Pallas, 1775]) were recorded in

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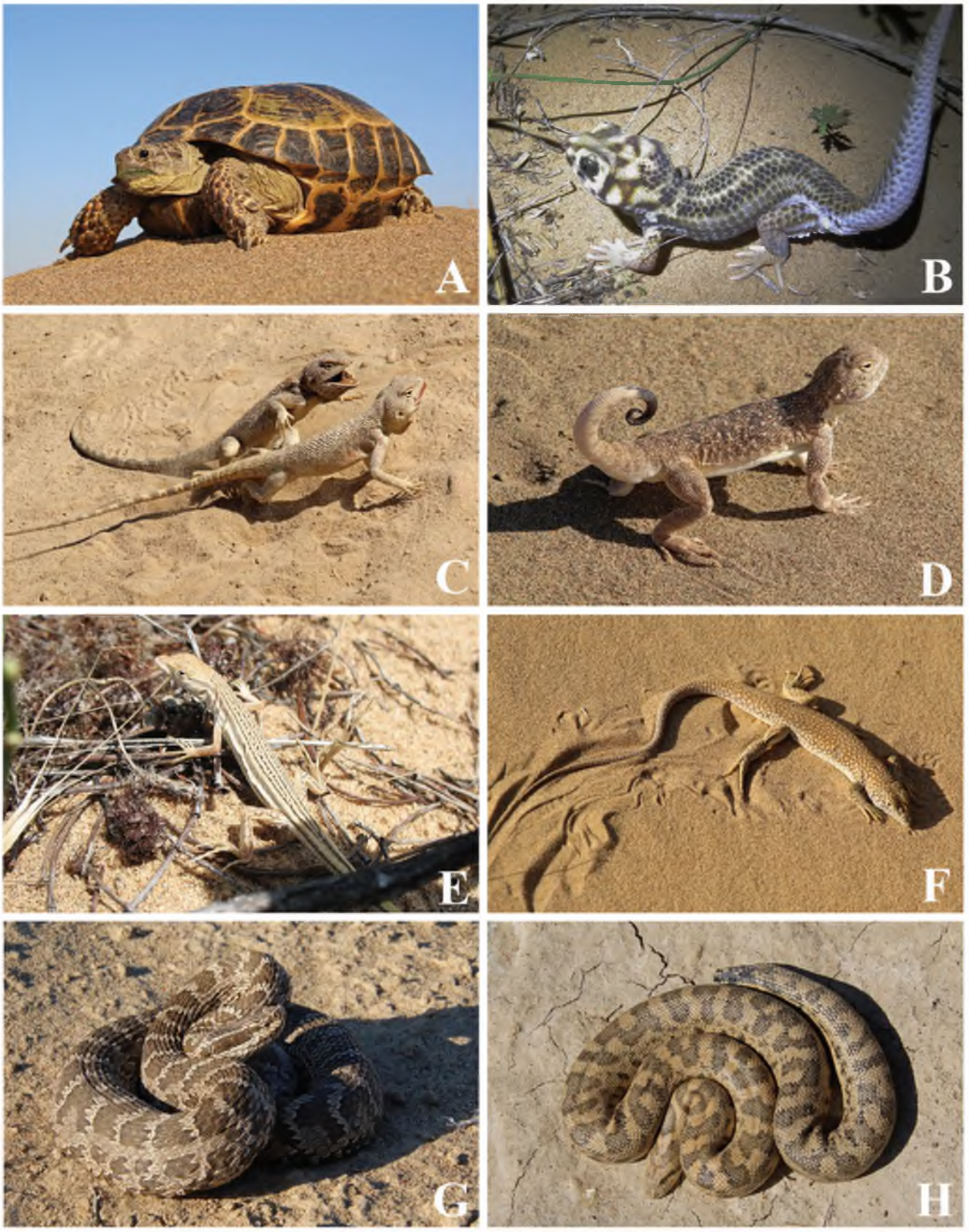

FIG. 2. Some reptile species of the Muyunkum Desert: A) *Testudo horsfieldii*; B) *Teratoscincus scincus*; C) *Trapelus sanguinolentus*; D) *Phrynocephalus mystaceus*; E) *Eremias scripta*; F) *Eremias grammica*; G) *Gloydius halys*; H) *Eryx tataricus*.

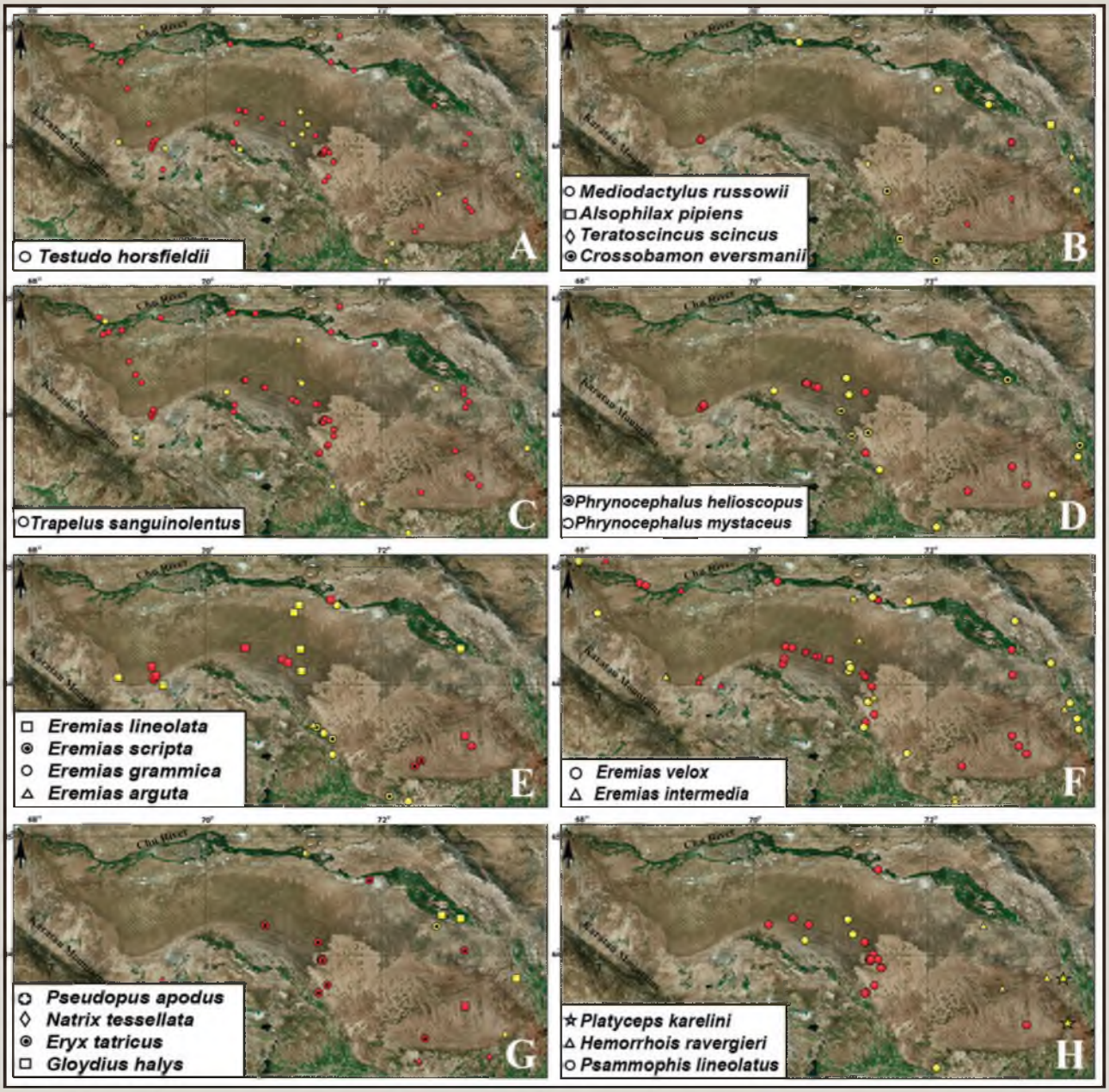

FIG. 3. Distribution of reptiles in the Muyunkum Desert (yellow dots: literature data; red dots: data collected during this study).

areas adjacent to the desert (Table 1, Fig. 2). *Pseudopus apodus* is included in the Red Book of Kazakhstan; *Testudo horsfieldii* and *Eryx tataricus* (Lichtenstein, 1823), in Appendix II CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). The Central Asian turtle is listed in the IUCN Red List (Vulnerable, VU).

Distribution.—The most common species are *T horsfieldii* and *T sanguinolentus* (Fig. 3A, C). In contrast, *Mediodactylus russowii* (Strauch, 1887), *Eremias scripta* (Strauch, 1867), *Gloydius halys* (Pallas, 1776), and *H. ravergieri* (Fig. 3B, E, G, H) are rare. *Phrynocephalus mystaceus, E. intermedia, E. lineolata, E. velox, Eryx tataricus,* and *P. lineolatus* (Brandt, 1838) were observed in the central, southern, and eastern parts of the Muyunkum Desert, and are practically not seen at all in the western part. *Eremias grammica* was registered in the southwest and southeast parts of the desert but not in the central and northern parts (Fig. 3E). The tadpoles of *Bufotes perrini* were observed in artesian well areas in the northwestern part of Muyunkum and in a small lake situated in the western part of the desert; two adult specimens were found in the central and western parts of the desert.

Habitats.—With the exception of open dunes and lake-marshy lowlands, *T horsfieldii* has been found in all habitats, including in the vicinity of salt pans. *Trapelus sanguinolentus* was found in the semi-fixed and fixed sands with calligonum bushes and saxaul trees, saxaul forest, and at the edge of salt pans. *Teratoscincus scincus, P. mystaceus, E. lineolata, E. scripta,* and *E. grammica* inhabited open dunes and/or the area of exposed sand on the semi-fixed sand massifs (Fig. 4A, B). *Teratoscincus scincus* and *P. mystaceus* were also found on roads at the places with dispersed sand, at a distance of up to 3 km from an open dune (Fig. 4F). *Eremias velox, E. intermedia,* and *P. lineolatus* were recorded on semi-fixed sands with small patches of bare sand, calligonum,

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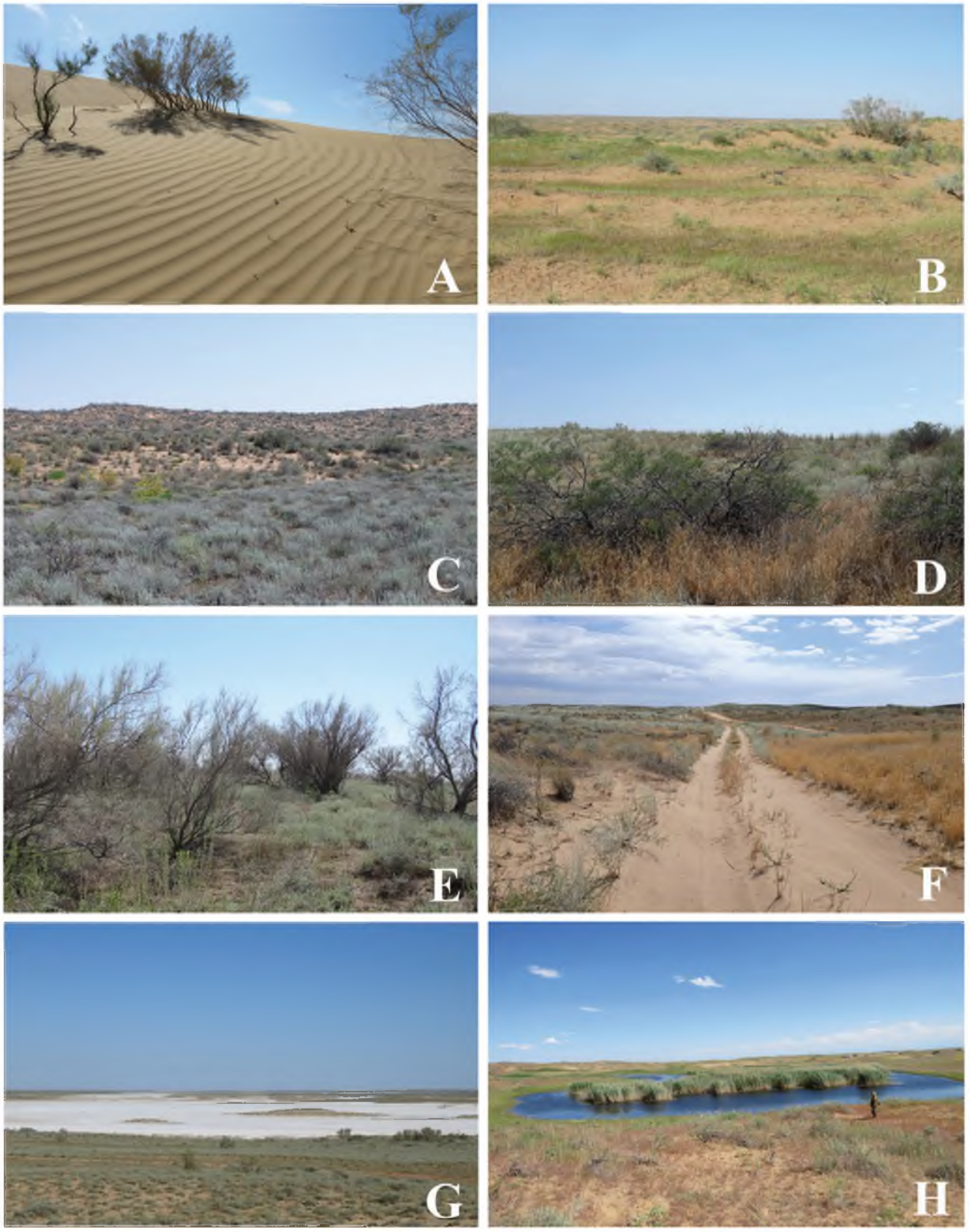

FIG. 4. Habitats of the Muyunkum Desert: A) open dunes; B) semi-fixed sands with exposed patches; C, D) fixed sands; E) saxaul forest; F) roads with dispersed sand; G) salt pans; H) unpaved lake-marshy lowlands with reed beds and sedge meadows.

TABLE 1. Summary list of herpetofauna from the Muyunkum Desert and surrounding areas.

Species	Muyunkum Desert	Surrounding areas	Literature data	This study
Bufotes perrini Mazepa et al., 2019	+	+	+	+
Testudo horsfieldii Gray, 1844	+		+	+
Ablepharus deserti Strauch, 1868		+	+	
Crossobamon eversmanni (Wiegmann, 1834)	+		+	
Alsophylax pipiens (Pallas, 1827)		+	+	
Mediodactylus russowii (Strauch, 1887)	+		+	+
Teratoscincus scincus (Schlegel, 1858)	+		+	+
Trapelus sanguinolentus (Pallas, 1814)	+	+	+	+
Phrynocephalus helioscopus (Pallas, 1771)		+	+	
Phrynocephalus mystaceus (Pallas, 1776)	+		+	+
Eremias velox (Pallas, 1771)	+	+	+	+
Eremias intermedia (Strauch, 1876)	+	+	+	+
Eremias lineolata (Nikolsky, 1897)	+		+	+
Eremias scripta (Strauch, 1867)	+		+	+
Eremias arguta (Pallas, 1773)		+	+	
Eremias grammica (Lichtenstein, 1823)	+		+	+
Pseudopus apodus (Pallas, 1775)		+		+
Platyceps karelini (Brandt, 1838)	+		+	
Hemorrhois ravergieri (Menetries, 1832)	+		+	+
Psammophis lineolatus (Brandt, 1838)	+		+	+
Natrix tessellata (Laurenti, 1768)		+	+	
Eryx tataricus (Lichtenstein, 1823)	+		+	+
Gloydius halys (Pallas, 1776)	+	+	+	+

and sand acacia shrubs. *Mediodactylus russowii* was detected on a saxaul tree at a large open dune on the southwest edge of the desert and in a saxaul forest in the eastern part of the Muyunkum (Fig. 4E). *Eryx tataricus* was observed mainly in the sands fixed by cereals, shrubs of sand acacia, and saxaul trees. *Pseudopus apodus* was recorded on the road along a farm field near the Muyunkum Desert.

Number of individuals and population density.—In terms of numbers, *E. velox*, *T. sanguinolentus*, and *T. horsfieldii* (in decreasing order) were the most frequently encountered (Fig. 5). They were followed by the following reptile species: *P. mystaceus*, *T. scincus*, *P. lineolatus*, *E. tataricus*, and *E. intermedia*. *Mediodactylus russowii*, *E. scripta*, *G. halys*, and *H. ravergieri* were recorded on a few occasions.

Fig. 6 shows the density graphs for some reptile species. The density of *T. horsfieldii* in the southwestern part of the sands is slightly higher (16/ha) than in the eastern one. On altered habitats near abandoned sheepfold sheds, a higher density (up to 26.64/ha) was noted. The population density of *T. sanguinolentus* averaged 20.5/ha, but in some areas reached 40–53.2/ha. Like the Central Asian Tortoise, the density of the steppe agama turned out to be lower in the eastern part of the desert.

The population density of *P. mystaceus* was 5.28–30.0/ha. In some patches of exposed sand in the central part of the Muyunkum Desert, there were up to 10 specimens per 40 m^2, which, when recalculated, is more than 1000/ha (due to the scale in Fig. 6, we do not give these data).

We calculated the density of *T. scincus* at only several localities in the southwestern and southeastern parts of the sands. On a large dune in the southwestern part of the sands, there were five

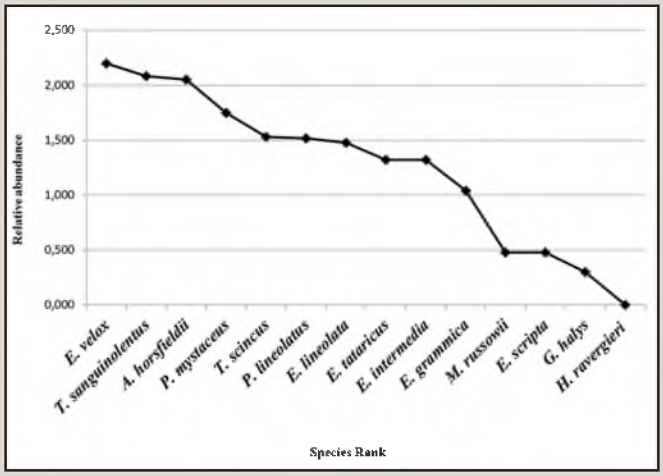

FIG. 5. The rank/abundance or Whittaker plot of reptiles in the Muyunkum Desert and surrounding areas. The ordinates on the logarithmic scale (log_{10}) show the number of individuals, and the x-axis shows the ranked sequence of species from the most to the least abundant.

adults and 16 semi-adult individuals, which yielded a density estimate of 84/ha. By contrast, in the southeastern area at three different sites we obtained density estimates of 19.9/ha, 5.2/ha, and 39.9/ha.

Eremias velox was the dominant species in the eastern part of the sands. Its density varied between 1.3–49.9/ha (Fig. 6). At the same time, areas of very high density were observed on the order of 240–400/ha (due to the scale in Fig. 6, we did not provide these data).

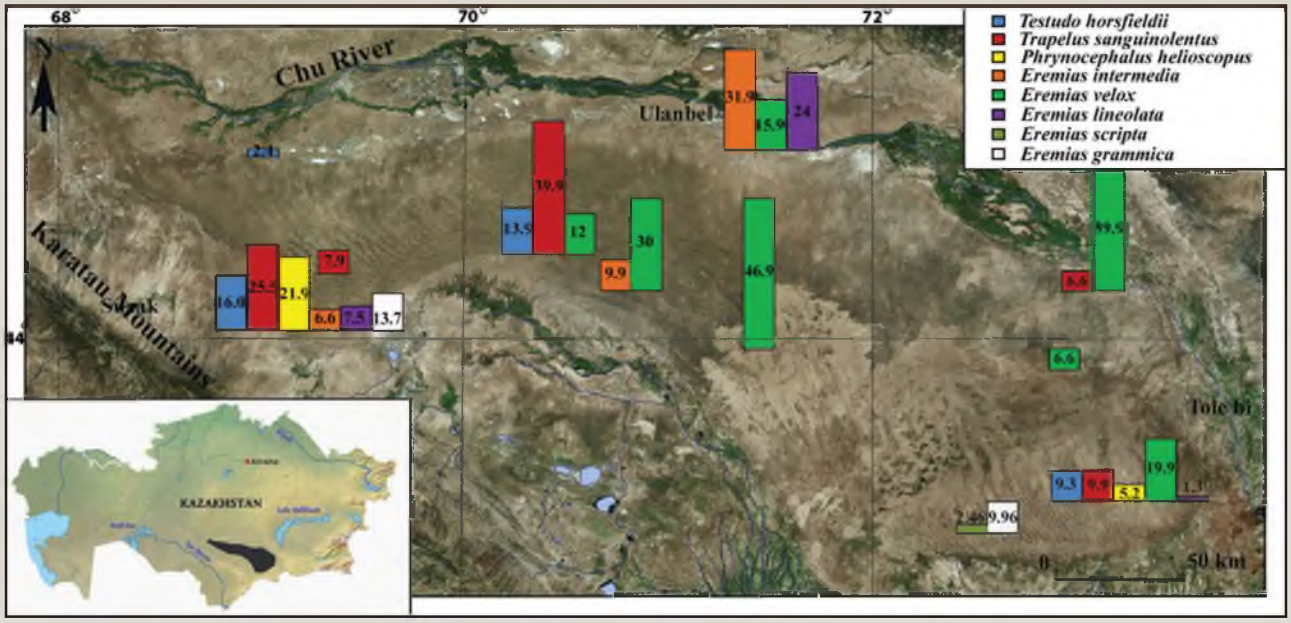

FIG. 6. Population density of some species of reptiles in the Muyunkum Desert.

Eremias grammica was recorded at two localities in the southwest and southeast parts of the desert, with the population density of 13.7 ± 3.7 (4.9–19.9) and 9.96/ha, respectively. *Eremias scripta* was rare and the population density in the southeast part of sands was 2.46/ha. *Eremias lineolata* is a common species, with density estimates of 7.5–24.0/ha. In the southern part of the sands, there were patches of sand on which we observed up to 9 specimens in an area of 25 m^2.

Increased occurrence of *P lineolatus* was also observed in the southern and southeastern parts of the desert (7.9–12.0/ha). Density estimates for *E. tataricus* was slightly lower—6.0 and 9.0/ha.

DISCUSSION

The results of the literature review and our obtained data showed that one species of amphibian and 16 species of reptiles were found to inhabit the Muyunkum Desert; and another six species present in surrounding areas. We did not record six species mentioned in the literature relating to the region: *Crossobamon eversmanni* (Wiegmann, 1834) (Paraskiv 1956; Golubev 1990; Brushko 1995; Borkin et al. 2007), *Alsophylax pipiens* (Pallas, 1827) (Brushko 1995; Shcherbak et al. 1997), *Phrynocephalus helioscopus* (Pallas, 1771) (Brushko 1995), *Ablepharus deserti* Strauch, 1868 (Eremchenko et al. 1999), *Eremias arguta* (Pallas, 1773) (Shcherbak 1974), and *Platyceps karelini* (Brandt, 1838) (Paraskiv 1956). Information on records of *Varanus griseus* Daudin, 1803 have appeared periodically (Brushko 1995; Chirikova et al, 2019), but our studies show that the *V. griseus* does not inhabit the Muyunkum.

The number of reptile species in the Muyunkum Desert is 31.4% of the total number of reptile species of Kazakhstan (Dujsebayeva 2013). The herpetofauna is quite homogeneous as to its origin: 87.5% of it is composed of Turan elements. Only *G. halys* and *H. ravergieri* belong to other complexes. That is, the herpetofauna of this desert is mainly characterized by true desert species (Lowe 1989). Unlike the Kyzylkum (Brushko 1995; Zima and Chirikova 2010), such Sahara-Sindian species as *V. griseus* and *Spalerosophis diadema* (Schlegel, 1837) are not found in Muyunkum. Due to the northern location of the desert, there are no species of the Iranian-Afghan, Kazakh-Mongolian, or other complexes typical of more southern deserts of Central Asia (Bogdanov 1965; Shcherbak 1994). *Phrynocephalus guttatus* (Gmelin, 1789) and *Phrynocephalus interscapularis* Lichtenstein and Martens, 1856, the representatives of the Central Asian fauna, are also not found in Muyunkum. However, according to Dunayev (2009), *P guttatus* lived in the Muyunkum in the Lower and Middle Quaternary Period. The Muyunkum Desert is poorer than the sandy deserts of the Northern Caspian region (Nakarenok 2002) and the Northern Aral region (Lobachev et al. 1973; Dinesman 1953), where steppe elements of the herpetofauna are included.

In general, three species—*E. velox, T. sanguinolentus,* and *T. horsfieldii*—dominate in the Muyunkum Desert (Figs. 3, 5). *Trapelus sanguinolentus* and *T. horsfieldii* dominate in the western part of the sands and *E. velox* in the central and eastern parts. The density of *T. horsfieldii* in some areas was higher that earlier estimates (Brushko and Kubykin 1981; Bondarenko et al. 2008). Vtorov and Pereshkolnik (1970) reported a low density of *E. velox* (2/ha) in the southern area of Muyunkum compared to the congeneric *E. grammica* (18/ha). Because their counts were conducted in September, such results can be explained as the result of decreased activity. However, our surveys—conducted at peak activity—indicate that in southeastern part of the desert, the numbers of *E. velox* are declining, while *E. grammica* is increasing, and in the southwestern part *E. velox* is replaced by *E. grammica* (Fig. 6).

The population density estimate we obtained for *T. scincus* in the southeastern part of the desert is comparable with data obtained earlier by Borkin et al. (2007) for the southern edge of the sands. In the southeastern part, the density was slightly higher. We attribute this to fewer suitable habitats in this part of the desert and as a result, a high concentration of lizards on the areas that are suitable for them.

We found *T. horsfieldii, T. scincus, T. sanguinolentus, E. lineolata, E. velox, E. grammica, P lineolatus,* and *E. tataricus* in new locations, extending our understanding of their

distributions in this desert (Fig. 3) (Brushko and Kubykin 1981; Brushko 1995; Borkin et al. 2007; Kubykin and Brushko 1998). Regarding distribution patterns, species can be divided into the following groups: 1) ubiquitous; 2) patchy widespread; 3) known from single records; 4) living in areas adjacent to the Muyunkum Desert and able to penetrate its edges.

Testudo horsfieldii and *T. sanguinolentus* belong to the first group. These species are widespread in the Muyunkum Desert, inhabit various habitats, and make up a dense population. The northernmost population of *T. horsfieldii* inhabits this area. Bondarenko and Dujsebayeva (2012) assumed that *T. horsfieldii* within Muyunkum included two subregional groups: "Ashchikol-Chu" and "Talas-Muyunkum." Having evaluated all available information, we conclude that the distribution of the Central Asian Turtle is uniform throughout the Muyunkum.

Bufotes perrini, P. mystaceus, T. scincus, E. velox, E. intermedia, E. lineolata, E. tataricus, and *P. lineolatus* are members of the second group. These species are closely linked to certain biotopes, which in turn determines the mosaic nature of their distribution.

The third group includes *Crossobamon eversmanni* (Wiegmann, 1834), *M. russowii, E. scripta, E. grammica, P. karelini, H. ravergieri,* and *G. halys.* All these species are known only from single records mainly from the periphery of the sands (Fig. 3) (Paraskiv 1956; Brushko 1995; Borkin et al. 2007; IZK and own collected data). The localities of *C. eversmanni, M. russowii* and *E. scripta* in the Muyunkum Desert are the northernmost for these species (Sindako and Eremchenko 2008). *Gloydius halys* was known from the northeast periphery of the Muyunkum (IZK, Kubykin and Brushko 1998); and we also found it in the eastern part of the desert (Fig. 3G). Most likely *G. halys* entered the Muyunkum Desert from the Karatau and Zhambyl mountains, and from the Betpak-Dala Desert where it is a common species (Kubykin and Brushko 1998). *Hemorrhois ravergieri* was recorded along the northeastern edge of the desert and can be found along the Chu River valley (Golubev 1990) and in lake-marshy lowlands in the eastern part of the desert.

The fourth group includes *A. pipiens, P. helioscopus, A. deserti, E. arguta, P. apodus,* and *N. tessellata.* Most of these species are sclerobionts, with single records known from surrounding areas or the edge of the sand massif (Paraskiv 1956; Brushko 1995; Shcherbak et al. 1997; Eremchenko et al. 1999; this study) (Fig. 3). Due to the peculiarities of their biology, these species do not penetrate deep into sandy areas and they should not be considered typical inhabitants of the Muyunkum Desert.

The uneven distribution of reptiles in the Muyunkum is primarily due to climatic features. In the western part of sands, the average annual precipitation is less and sunshine duration is longer compared to the eastern part (Medeu 2010). This also determines the composition of vegetation: Black Saxaul communities are located in the western part, White Saxaul communities in combination with psammophytic-shrub communities in the central and northern parts of the desert (Bedareva 2009). Another important factor is surface relief: the presence of sand dunes and semi-fixed sands with patches of bare sand in the southern part of the Muyunkum Desert positively influences the distribution of psammophilous reptile species, in particular *E. grammica* and *P. mystaceus.* More widespread pasture farming in the southeastern and central parts also has a positive impact on the distribution of some reptile species. Because of livestock grazing, sand is dislodged and further wind erosion occurs, which leads to the formation of suitable habitats for psammophiles (Nakarenok 2002).

Based on the results of this study, it appears that herpetofaunal diversity of this desert is relatively impoverished compared to sandy deserts of the Northern Caspian, the Northern Aral region, and southern sand deserts of Central Asia. The distribution of reptiles in the Muyunkum Desert is uneven due to differences in climate, relief, and degree of grazing in the western, eastern, and southern parts of the desert. Additional surveys are needed to cover a wider range of habitats, such as lake-marshy lowlands and clay areas, to better understand the herpetofauna of Muyunkum.

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Appendix 1

List of inventory numbers of collections.

IZK: *Testudo horsfieldii*: 97/3127, 109/1252–1255; *Trapelus sanguinolentus*: 55/744–755, 106/1231–1239, 106/1242–1243, 267/2867–2868, 351/3857–3858; *Phrynocephalus helioscopus*: 83/981-988, 371/4139; *Phrynocephalus mystaceus*: 82/978–980, 107/1244–1246, 271/2912–2915, 190/1941–1944, 803/1; *Mediodactylus russowii*: 18/4795; *Eremias velox*: 269/2879–2902, *Eremias intermedia*: 77/972–973, 716/1–2, 754/1–10, 777/1–7; *Eremias grammica*: 81/977, 755/1–4; *Eremias lineolata*: 739/1–5, 802/1–3; *Natrix tessellata*: 207/2153–2154; *Hemorrhois ravergieri*: 104/1227–1228; *Platyceps karelini*: 105/1229; *Eryx tataricus*: 9/1226; *Psammophis lineolatus*: 800/1.

ZMMU: *Eremias velox*: R-6863, R-6866, R-7947; *Eremias intermedia*: R-6862; *Eremias lineolata*: R-6860; *Eremias scripta*: R-6861.

ZISP: *Eremias intermedia*: 13479; *Gloydius halys*: 14812; *Eryx tataricus*: 17299.