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Tarentola annularis (Squamata: Phyllodactylidae): a new invasive species in Israel

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Since the Mid-Miocene, the land that is now Israel served as a land bridge connecting Africa and Eurasia. This is reflected by the presence of fauna and flora indigenous to both continents (Haas & Werner 1969, Tchernov 1992). Twelve Gekkota species, of various origins, have been documented in Israel (Bar & Haimovitch 2011). All but one, *Cyrtopodion scabrum* (Heyden, 1827), of which the distributional status in Israel is doubtful (natural dispersal or introduction), are recognized as native to Israel.

In the last few years, there have been sightings of unusually large geckos in Kibbutz Ein Gedi (31.45° N, 35.38° E, 280 m below sea level) in the Judean Desert, overlooking the Dead Sea (Fig. 1). These were assumed to be Sinai Fan-Fingered Geckos (Phyllodactylidae: *Ptyodactylus guttatus* Heyden, 1827), one of the largest gecko species in Israel, which is characterized by a widening of the distal region of the fingers, under which it has adhesive toepads.

During a reptile survey conducted at night in May 2012, we observed large, robust geckos at this locality, which appeared morphologically different from the known *P. guttatus* (specimens of which were caught just outside the settlement), but failed to catch them. In October 2014, S.J. captured two specimens and secured a tail of a third on house walls in Kibbutz Ein Gedi. We examined the specimens in the laboratory, both morphologically and genetically, in order to identify the geckos and their origin.

We identified the specimens as belonging to the genus *Tarentola* Gray, 1825 based on size and toe morphology (Schleich et al. 1996). *Tarentola* Wall Geckos are members of the family Phyllodactylidae (Gamble et al. 2008; as are *Ptyodactylus* Geckos), and the genus is comprised of 31 recognized species (Uetz & Hošek 2016). *Tarentola* species are distributed around the central and western parts of the Mediterranean basin, in parts of the Sahara and Sahel regions, the northern Sub-Sahara region, the Macaronesian islands, and the West Indies (Schleich et al. 1996, Baha el Din 2006, Sindaco & Jeremčenko 2008, Jirků et al. 2010). They occur in a wide range of habitats and can be found in desert, subtropical, tropical, and Mediterranean climates. Most species are primarily nocturnal and tend to climb and occupy rocky surfaces, trees, human constructions, ruins etc. (Carranza et al. 2000, Schleich et al. 1996).

Very little research has been done concerning invasive reptiles in Israel and their effects on indigenous species. The Red-Eared Slider (*Trachemys scripta elegans*) and the Rough-Tailed Gecko (*Cyrtopodion scabrum*) are considered invasive, although the latter may have been expanding its distribution into Israel naturally (B. Shacham, pers. comm.; see Kornilios et al. 2010 for the possibility of *Chalcides ocellatus* also being invasive in the eastern Mediterranean). We aimed to identify the gecko specimens to species level, pinpoint their origin, and conclude whether this new record constitutes an invasion, a natural occurrence, or a range extension.

We used both molecular and morphological examination techniques. The Ein Gedi specimens (deposited in the Steinhardt Museum of Natural History, Tel-Aviv University [SMNHTAU] as TAU.R17103, TAU.R17104, and TAU.R17105) were sequenced for the ribosomal 12S rRNA (12S) mitochondrial gene fragment (amplified using the 12Sa and 12Sb primers, Kocher et al. 1989). The phylogenetic position of the Israeli specimens was assessed using 152 sequences from 20 available species of the genus *Tarentola* retrieved from GenBank, eight sequences of the three *Ptyodactylus* species known from Israel, and five sequences of *Hemidactylus angulatus* Hallowell, 1854 to root the tree. GenBank codes and references are presented in Supplementary Table 1. Sequences were aligned using the online application of MAFFT v. 7 (Katoh & Standley 2013) with default parameters. JModelTest v. 2.1.5 (Guindon &

Gascuel 2003, Darriba et al. 2012) was used to select the most appropriate model of sequence evolution under the Akaike information criterion (Akaike 1973) Phylogenetic analysis was performed with BEAST v. 1.8.0 (Drummond et al. 2012). Models, priors, and parameter specifications applied were as follows (otherwise by default): GTR+I+G model; relaxed uncorrelated lognormal clock; coalescent tree prior with a random starting tree; base substitution prior Uniform (1, 100); alpha prior Uniform (0, 10); clock rate prior Uniform (substitution rate fixed to 1). Three individual runs were performed for 5×10^7 generations with a sampling frequency of 5×10^3, and the results were combined to generate the consensus tree after discarding 10% of the samples from each run as burn-in. The convergence of runs was assessed using Tracer v. 1.5 (Rambaut & Drummond 2009). LogCombiner and TreeAnnotator (both available in the BEAST package) were used to generate the ultrametric tree.

Characters for the morphological identifications of the Ein Gedi *Tarentola* specimens were selected based on previous studies of the genus and compared to the characters of *Tarentola* species taken from the literature (Schleich et al. 1996, Baha el Din 2006) and personal observations. These characters included: snout–vent length (SVL); number of lamellae and enlarged scales under the first and fifth toes; shape and arrangement of dorsal tubercles and scales; presence/absence of enlarged scales between mental shield and gular scales; arrangement of scales around the nostril; dorsal colour patterns. Measurements were taken from the left side using a digital calliper with an accuracy to the nearest 0.01 mm.

The results of the 12S rRNA phylogenetic analysis, based on 308 bp, confirm that the three specimens from Israel belong to the genus *Tarentola* (Supplementary Fig. 1). Although the phylogenetic relationships among the species within *Tarentola* are not supported (Supplementary Fig. 1), the three samples from Israel cluster with strong support with three specimens of *Tarentola annularis* (Fig. 1 and Supplementary Table 1). All six sequences of *T. annularis* (our three and three from GenBank: two from Egypt and one of unknown geographic origin) are identical.

The morphological comparisons within the genus complement our genetic results and confirm the identification of the three specimens from Israel as *Tarentola annularis*. The morphological comparisons to other specimens of *Tarentola* (values taken from the literature; Schleich et al. 1996, Baha el Din 2006) present values that agree well with those of *T. annularis*: the largest Israeli *Tarentola* specimen captured (TAU.R17103, male; SVL, 103.9 mm; weight 39.6 g; but S.J. observed even larger individuals in Kibbutz Ein Gedi) is within the range known for the species (males: 121 mm; females: 99 mm; maximum of 140 mm; Schleich et al. 1996). It is much longer and, especially, heavier than any Israeli *Ptyodactylus* (*P. guttatus*: max. SVL 94 mm, max. weight 24.2 g, both *P. hasselquistii* (Donndorff, 1798) and *P. puiseuxi* Boutan, 1893: 90 mm and 18 g; data from Meiri 2010, SMNHTAU, and the authors' personal field measurements). All specimens have four distinctive white round spots surrounded by black rings on

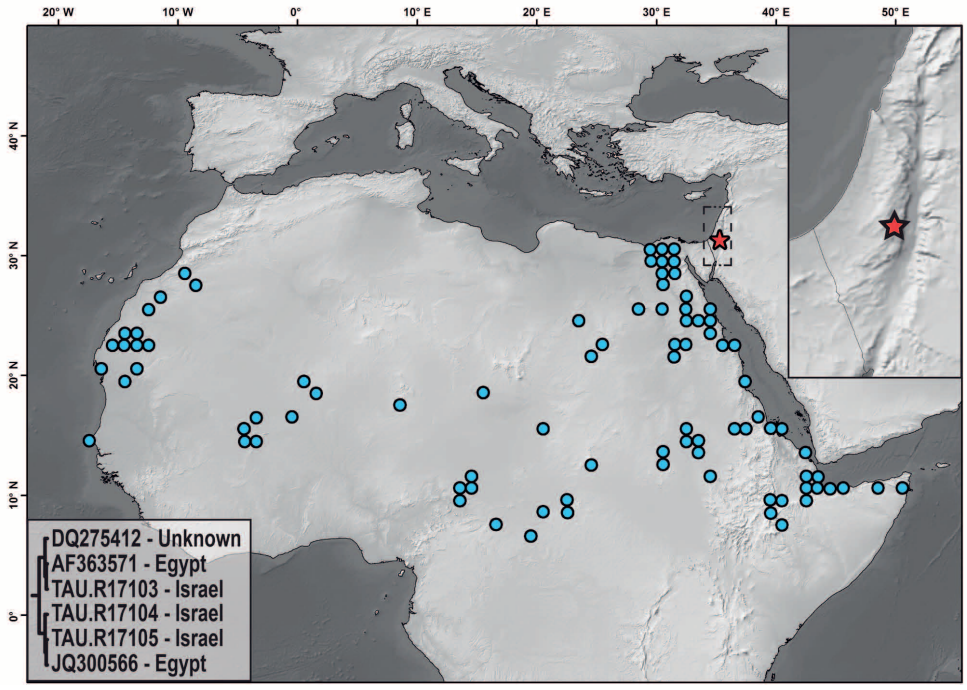

Figure 1. Distribution map of *Tarentola annularis annularis* (modified from Sindaco & Jeremčenko 2008), with the new locality in Israel indicated by a star. The *Tarentola annularis* lineage, including localities, reconstructed from a Bayesian phylogenetic analysis, is visualized in the lower left corner (for the full tree see Supplementary Fig. 1).

their dorsa (unique for the subspecies *T. annularis annularis*) and ca 14 longitudinal rows of tubercles (Fig. 2A). The nostril is surrounded by three nasal scales and the first supralabial (Fig. 2B). The tip of the rostral slightly touches the nostril, in agreement with Baha el Din (2006), but see Schleich et al. (1996). The postmentals are smaller than the gulars (Fig. 2D). The dorsal side of the body is covered with smooth or weakly keeled tubercles, surrounded by medium sized scales (Fig. 2E). There are 22 and 29 lamellae under the first and fifth toes, respectively, well within the range of *T. annularis* (13–25 and 25–31, respectively; Schleich et al. 1996; Fig. 2F).

Based on the morphological and genetic data we thus identified the species from Ein Gedi as *Tarentola annularis annularis* (Geoffroy Saint-Hilaire, 1809). This is the first verified and accurate documentation of this species

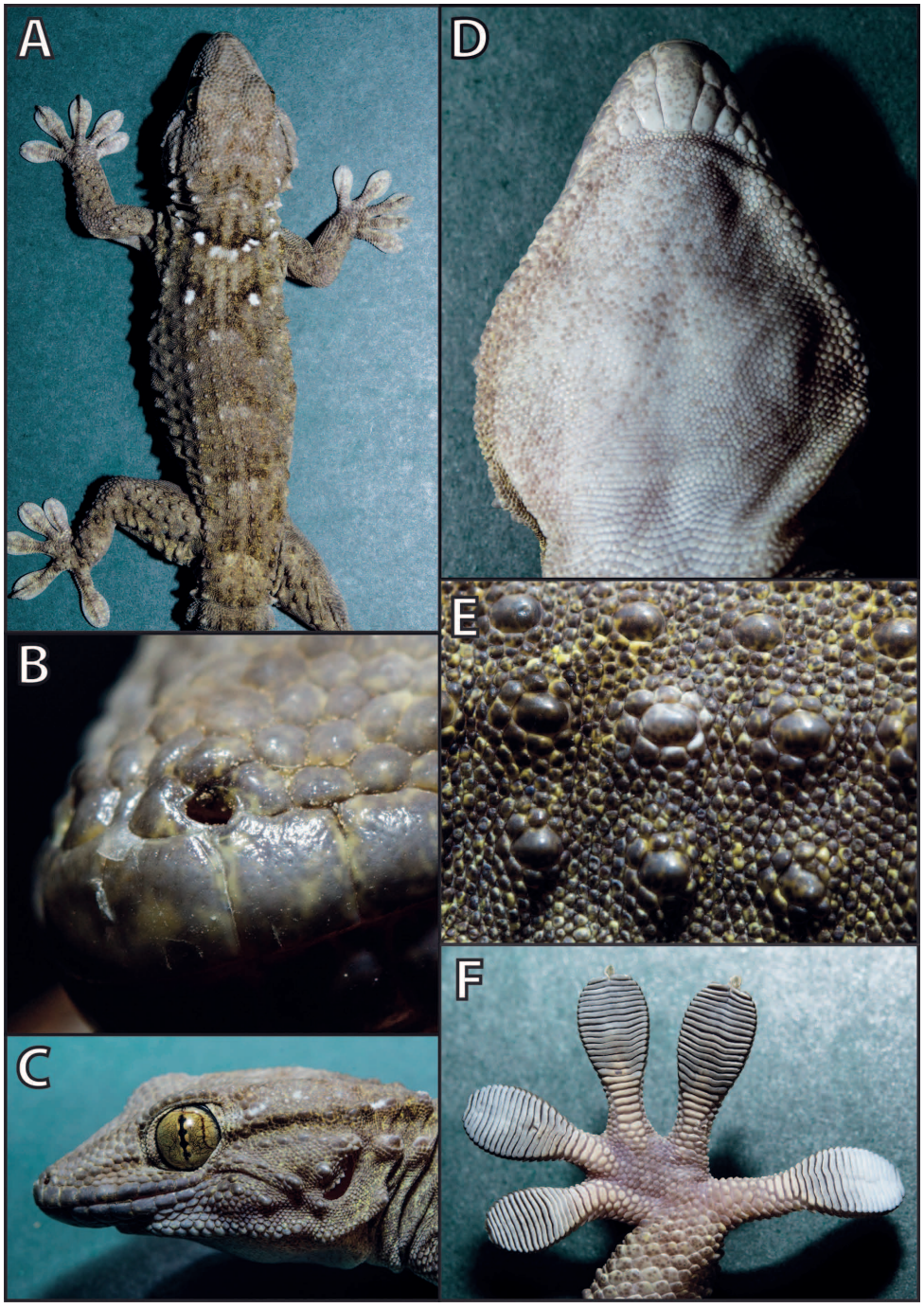

Figure 2. Specimen of *Tarentola annularis annularis* from Ein Gedi, Israel (TAU.R17103; male). (A) Dorsal view; (B) nostril; (C) head in lateral view; (D) head in ventral view; (E) dorsal tubercles; (F) ventral view of the toes.

from Israel and in Asia as a whole. Masood & Asiry (2012) claimed to have found *T. annularis* in Saudi Arabia, but this was later questioned by Aloufi & Amr (2015). The American Museum of Natural History holds a specimen (AMNH 27362) that was identified as *Tarentola annularis*, collected in 1923 at "Ramleh, Palestine". The closest known modern place name in Israel is Ramla (31°56' N, 34°52' E): a city in the Mediterranean region of central Israel. We strongly suspect that such an isolated locality, well outside the distribution range of *T. annularis*, from where this species was never reported before or since, is unlikely to be the true origin of this specimen. Until our findings, no other sightings of this species in Israel have been reported.

Tarentola annularis is widely distributed, occurring in the Sahel and subtropical zones of Africa (Fig. 1; Schleich et al. 1996, Baha el Din 2006, Sindaco & Jeremčenko 2008, Jirků et al. 2010). The species is composed of two subspecies, *T. annularis annularis* (Geoffroy Saint-Hilaire, 1809) from North Africa and *T. annularis relicta* Joger, 1984 from the northern Sub-Saharan region. It is phylogenetically close to the Saharian-Sahelian *T. ephippiata* (Carranza et al. 2002, Rato et al. 2012). *Tarentola annularis* is also known from a few localities in southern Florida, USA, where it has been introduced as a result of the pet trade (Krysko & Daniels 2005).

While *Tarentola annularis* occurs throughout North Africa including Egypt, rumours of sightings in the Sinai Peninsula have been refuted (Werner 1988, Baha el Din 2006). Our sightings of *T. annularis* so far are restricted to Kibbutz Ein Gedi, where these geckos can be found in great abundance on the walls of houses (more than 10 individuals can be seen on a ~10 × 5 m wall at night; authors' pers. obs.). However, since we collected the specimens, amateur Israeli herpetologists have spotted geckos matching the description of *T. annularis* also in the adjacent Arugot Wadi, inside the Ein Gedi Nature Reserve (A. Bar pers. comm.).

Tarentola annularis is very popular in the pet trade, and thousands of specimens are exported from Egypt annually to worldwide destinations (Baha el Din 2006). An Ein Gedi resident kept some as pets about ten years ago (A. Bar pers. comm.). *Tarentola annularis* is a successful invasive species that has established stable communities in different parts of the United States, particularly Florida (Krysko & Daniels 2005). The distribution of this gecko in Israel is far from its nearest known localities in Egypt, despite parts of the Sinai Peninsula and southern Israel being climatically and topographically similar to Ein Gedi, and the proximity of the species' native range in Egypt, likely providing adequate habitat. The gap is likely real, as southern Israel and the Sinai Peninsula have been extensively surveyed over the years (Haas 1943, Barash & Hoofien 1956, Schmidt & Marx 1956, Arbel 1984, Werner 1982, 1987, 1988, Baha el Din 1994, Crochet 1997, Bouskila & Amitai 2001, Dolev & Petrolutzki 2002, Bar & Haimovitch 2011). This peculiar distribution pattern (Fig. 1), combined with its known invasive capabilities and presence in the Israeli pet trade, lead us to deduce that the Ein Gedi population of *T. annularis* is invasive. Because sequences of *T. annularis* are scarce in GenBank, and some are without known collection localities, we were unable to deduce the exact geographic origin of the introduced population.

Tarentola annularis is a large and aggressive species (Hoofien 1962, Crochet & Renoult 2008), clearly with a readiness to bite (painful pers. obs.). It feeds on a wide spectrum of vertebrate and invertebrate species, including the native Sinai Fan-Fingered Gecko, *Ptyodactylus guttatus* (Baha el Din 2006). It has even been documented predating on gerbils (Crochet & Renoult 2008). Furthermore, while we observed *P. guttatus* in Ein Gedi and its surroundings, they never shared the same wall with the larger *T. annularis*. Clearly, if left unchecked, this gecko has the potential to invade new habitats and outcompete and predate upon numerous native taxa. Further rigorous surveys are required to document the present extent of the invasion, and immediate and firm actions should be taken swiftly to eradicate the invasive population while still at its early stages.

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Supplementary material

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Supplementary Table 1. Information on the specimens used in this study and related GenBank accession numbers.

Supplementary Figure 1. Bayesian inference tree of *Tarentola*.