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RESULTS OF THE FIRST HERPETOLOGICAL SURVEY OF ISRAEL'S MEDITERRANEAN COASTAL ISLETS

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Small islets in the Mediterranean Sea are often home to reptiles, typically representing an impoverished sample of the continental fauna, yet with high population densities and signs of rapid morphological and behavioral evolution. In this paper, we present the first herpetofaunal survey of several small islet clusters in close proximity to the Mediterranean coast of Israel, only recently geologically separated from the mainland. We performed surveys of five islets during March of 2017 – 2018 and recorded the presence of five different species of reptiles on four of the surveyed islets. Species richness varied between 1 and 4 species, and appeared to be correlated with island area, with a distinct nested structure. Reptile species may have colonized the islets by natural dispersal from nearby coastal populations, or by hitch-hiking on fishing boats and similar methods of human-assisted dispersal. Alternatively, the recorded reptiles may represent relictual populations from earlier geologic periods, when lower sea-levels supported continuous land-bridges between the islets and the mainland. These insular reptile populations require further study to establish the exact means of colonization and describe if and how they differ from mainland populations. We stress the importance of such small Mediterranean islets such as these as centers of unique biodiversity and encourage future study and conservation action aimed at them and similar islets.

Keywords: lizards; Lacertidae; Gekkonidae; Scincidae; islands.

Islands have long been known as hotspots of biodiversity, hosting unique floral and faunal communities (Whittaker and Fernández-Palacios, 2007). The Mediterranean Sea contains many continental shelf islands, which formed when fluctuating sea levels isolated patches of land previously continuously connected to the mainland (Hsü et al., 1973; Lymberakis and Poulakakis, 2010). Therefore, they usually host a diminished sample of the continental fauna, with their smaller sizes supporting a lower richness of species (Triantis et al., 2012). However, the species that do occupy them are often extremely abundant, and display signs of rapid morphological and behavioral evolution (Pafilis et al., 2009a, 2009b; Raia et al., 2010; Li et al., 2014; Slavenko et al., 2015; Itescu et al., 2018). On the smallest islets, typically the only terrestrial vertebrates found are reptiles (Valakos et al., 2008).

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Israel's rich assemblage of reptiles includes 94 currently recognized species, roughly half of which occur in the Mediterranean climate zone (Bar and Haimovitch, 2011; Meiri et al. 2019). Many are phylogenetically close to, or are the same as, species that occur on small islets elsewhere in the Mediterranean Sea such as *Hemidactylus turcicus*, *Chalcides ocellatus*, and *Mediodactylus orientalis* (Kornilios et al., 2010; Moravec et al., 2011; Kotsakiozi et al., 2018).

Off the Mediterranean coast of Israel are several small islets, five of which are vegetated and have soil, and are potentially suitable to support reptiles. Similar to other islands and islets in the Mediterranean Sea, these continental-shelf islands are close to the mainland (less than 1 km distance from shore). Furthermore, they are relatively young, having been previously connected to mainland Israel as recently as ~4000 years ago, perhaps even later (Sneh and Klein, 1984; Sivan et al., 2001). Therefore, they are likely candidates to host several common reptile species from the Mediterranean climatic zone of Israel.

We conducted herpetological surveys of the five Israeli islets in 2017 and 2018 (Fig. 1). We visited

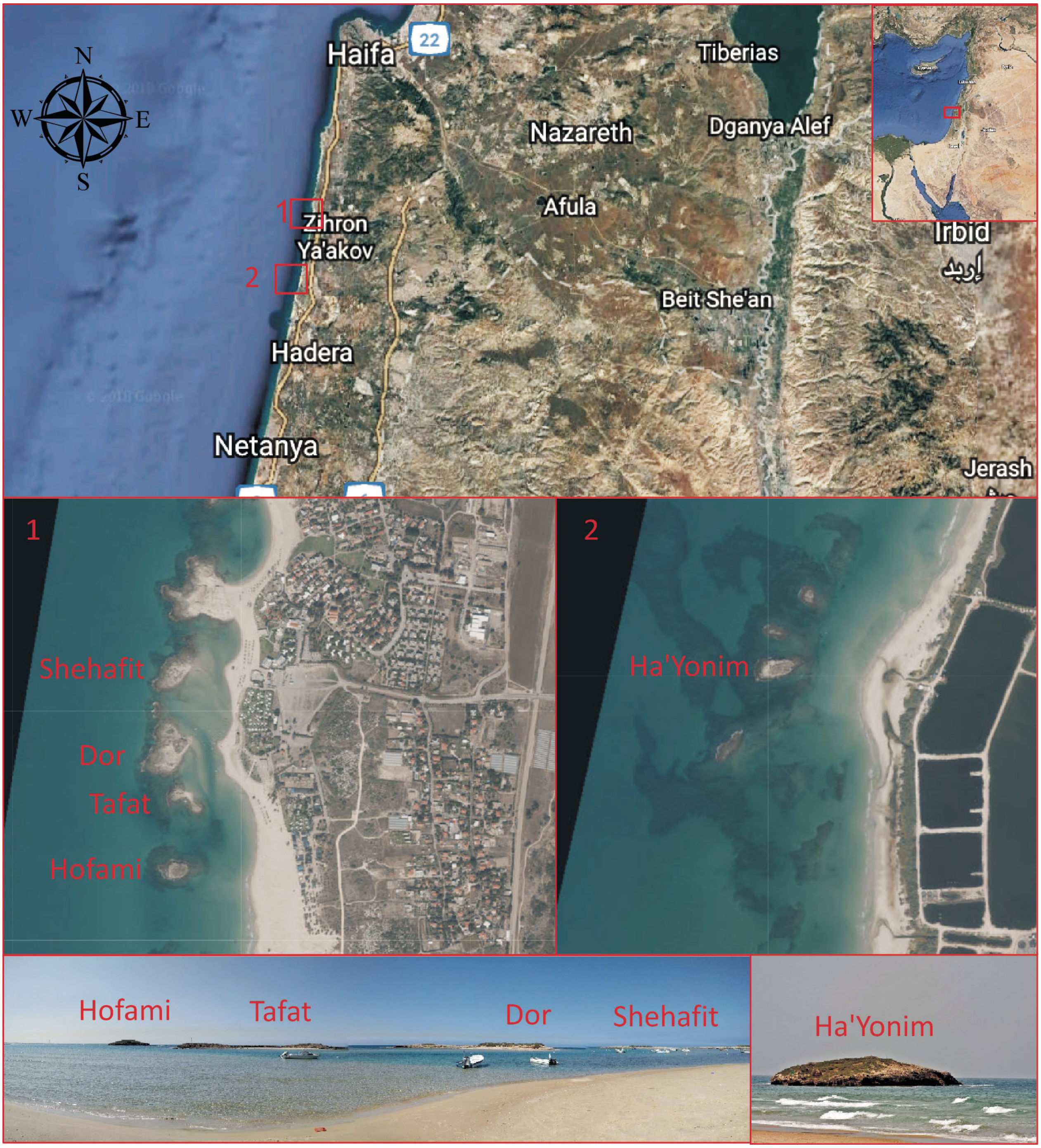

Fig. 1. A map of the Israeli Mediterranean coast and the sampled islets (top), and photos of the islets taken from the mainland (bottom).

Ha'Yonim Island (32.5554° N 34.9026° E; 2847.6 m^2), offshore from Ma'agan Mikhael, in March 2017 for a preliminary survey. Then, in March 2018 we surveyed Dor (32.6092° N 34.9146° E; 9429.3 m^2), Shehafit (32.6112° N 34.9145° E; 4372.5 m^2), Tafat (32.6080° N 34.9147° E; 2244.9 m^2), and Hofami (32.6059° N 34.9146° E; 2381.8 m^2) Islands off the coast of Dor, as well as revisited Ha'Yonim Island.

We spent roughly 1.5 h on each islet (three in total on Ha'Yonim Island) surveying for reptiles, during the

TABLE 1. Details of the Surveyed Reptiles, Including Species, Islet, Date, SVL (mm), Tail Length (TL, mm), Weight (g), and Museum Catalogue Number if the Animal Was Collected

Species	Islet	Date	SVL	TL	Mass	Collection No.
Hemidactylus turcicus	Ha'Yonim	08/03/2017	35.5	30.7 r	1.1	
Chalcides ocellatus	Ha'Yonim	08/03/2017	97.2	37.6 r	15.6	
Hemidactylus turcicus	Ha'Yonim	08/03/2017	43.8	47.5 r	3.1	
Hemidactylus turcicus	Ha'Yonim	08/03/2017	47.3	49.5 o	3.4	
Hemidactylus turcicus	Ha'Yonim	08/03/2017	27.9	25.2 r	0.7	
Chalcides ocellatus	Ha'Yonim	08/03/2017	79.3	73.1 o	8.6	
Chalcides ocellatus	Ha'Yonim	08/03/2017	100.6	58.5 r	18.1	
Hemidactylus turcicus	Ha'Yonim	08/03/2017	32.2	23.1 r	1.1	
Chalcides ocellatus	Ha'Yonim	08/03/2017	88.1	88.1 r	14.1	
Chalcides ocellatus	Ha'Yonim	08/03/2017	101.0	73.0 r	17.1	
Chalcides ocellatus	Ha'Yonim	08/03/2017	79.8	54.9 r	9.1	
Chalcides ocellatus	Ha'Yonim	08/03/2017	92	90 o	21.6	SMNH R.18206
Chalcides ocellatus	Ha'Yonim	08/03/2017	113.2	c	22.1	
*Chalcides ocellatus**	Ha'Yonim	04/03/2018	NA	NA	NA	
Mauremys rivulata	Ha'Yonim	04/03/2018	NA	NA	8.6	SMNH R.18850
Hemidactylus turcicus	Shehafit	27/03/2018	34.1	37.7 o	1	
Acanthodactylus boskianus	Shehafit	27/03/2018	70.1	139 o	11.1	
Hemidactylus turcicus	Dor	27/03/2018	33.9	c	1	SMNH R.18854
Chalcides ocellatus	Dor	27/03/2018	94.7	62.7 r	14.8	
Hemidactylus turcicus	Dor	27/03/2018	40.9	c	1	
Hemidactylus turcicus	Dor	27/03/2018	45.8	36 r	2.2	
Hemidactylus turcicus	Dor	27/03/2018	50.4	34.9 r	3.2	
Hemidactylus turcicus	Dor	27/03/2018	51.8	42.8 r	3	
Hemidactylus turcicus	Dor	27/03/2018	49.6	46.3 r	2.9	
Hemidactylus turcicus	Dor	27/03/2018	42.6	38.7 r	1.8	
Hemidactylus turcicus	Dor	27/03/2018	38.7	43.1 o	1	SMNH R.18853
Chalcides ocellatus	Dor	27/03/2018	92.1	61.7 r	1	
*Acanthodactylus boskianus**	Dor	27/03/2018	NA	NA	NA	
*Ablepharus rueppellii**	Dor	27/03/2018	NA	NA	NA	
*Hemidactylus turcicus**	Hofami	27/03/2018	NA	NA	NA	

Notes. Under the TL column, the state of the tail is also annotated: o, original tail; r, regenerated tail; c, cut tail; * observed only, not measured.

morning and noon. On Ha'Yonim Island only, we uprooted vegetation in collaboration with the Israeli Nature and Parks Authority, to clear nesting grounds for Common Terns (*Sterna hirundo*). During the uprooting process, we uncovered reptiles hiding in the root systems of shrubs. In addition to this, and on all other sites, we visually searched for active reptiles during activity hours and overturned shelters such as rocks, debris, driftwood, fishing nets, etc. All reptiles were caught by hand and identified to species level.

We measured SVL to the nearest 0.1 mm using digital calipers, and mass to the nearest 0.1g using spring scales. All animals were released after measurements were obtained, apart from four dead individuals that were collected and deposited in the Steinhardt Museum of Natural History (SMNH) collections. Up to two tail tips from each species were collected from each islet under a permit from the Israeli Nature and Parks Authority and deposited in the SMHH tissue collections.

We recorded reptiles on four of the five surveyed islets (Table 1). Only Tafat Island, the smallest islet surveyed, lacked any reptiles. The most common reptile species observed was *Hemidactylus tucicus* (four islets), followed by *Chalcides occellatus* (three islets), and *Acanthodactylus boskianus* (two islets). Both *Ablepharus rueppellii* and *Mauremys rivulata* were recorded from one island each, but we must note that we did not observe any live, adult *M. rivulata*, and only found a single freshly dead juvenile specimen (which we collected for the SMNH collections). We think it is unlikely that a small islet with no freshwater sources could support a population of freshwater turtles. Rather, we think the specimen we found was probably hunted or scavenged on the mainland and brought to the islet by a resident bird, possibly

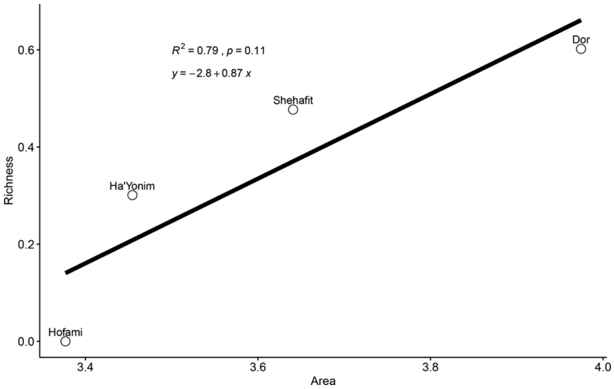

Fig. 2. Linear regression of $\log_{10}$ species richness against $\log_{10}$ island area (in m^2).

Corvus corax or nesting *Larus michahellis* — the ~200 m distance from the islet to the mainland is well within the foraging distance for *L. michahellis* (Arizaga et al., 2014).

We tested for a species-area relationship in the surveyed islands by fitting a log-log linear regression model of species richness against island area in R 3.5.1 (R Core Team, 2017). We calculated island areas using the Polygon tool in Google Earth (Google LLC, 2019). Species richness seems to increase with island area (Fig. 2). We omitted *M. rivulata* from this analysis since we do not consider it native on the islets. The log-log regression had a slope of 0.87, and R^2 of 79%. The regression was not significant, with a p-value of 0.11, but we note that the sample size for the regression is extremely low ($n = 4$).

Species composition on the islets follows a nested pattern, with the sole exception of *M. rivulata*. On the smallest islet inhabited by reptiles, Hofami island, we only found *H. turcicus*. The next largest islet, Ha'Yonim island, had *H. turcicus* and *C. ocellatus*. The next largest islet, Shehafit island, had the previous two species and, in addition, *A. boskianus*. Finally, the largest islet, Dor island, had the full assortment of four species; the previously mentioned three, as well as *A. rueppellii*.

Fig. 3. Photos of the surveyed animals: *a*, *Hemidactylus turcicus* from Ha'Yonim Island; *b*, *Chalcides ocellatus* from Ha'Yonim Island; *c*, *Acanthodactylus boskianus* from Shehafit Island; *d*, *Mauremys rivulata* from Ha'Yonim Island. *Ablepharus rueppellii* was observed but we were unable to photograph it.

In total, we managed to record five species of reptiles on the surveyed islets (Fig. 3), a somewhat remarkable result considering the islets' extremely small sizes, ranging from only 0.0024 to 0.0094 km^2. And yet, these seem large enough to sustain populations of multiple reptile species. It should also be noted that the actual area available to reptile activity on these islets might be even smaller than the areas we report here — the boundaries of the islets are bare rock and exposed to tidal movements and sea-spray. We did not record any reptiles on the unvegetated sections of the islets, and doubt that they make use of such hostile microhabitats.

The presence of multiple active individuals, including juveniles of all but *A. rueppellii*, lead us to conclude that the islets host viable populations. The question then remains — how did these species arrive on the islets? We propose three plausible scenarios: a) natural dispersal, b) human-assisted dispersal, and c) relictual populations.

Natural dispersal seems extremely likely considering the short distances from the mainland that are involved (~200 m or less). Although we do not know the saltwater tolerances or swimming capabilities of the surveyed species, rafting could also be a potential dispersal mechanism. In fact, the islets lie close to the mouths of two streams — Taninim stream (south of Ha'Yonim Island) and Daliya stream (south of the Dor Coast islets). The prevailing counter-clockwise sea surface currents in the Levantine basin of the Mediterranean Sea (Bergamasco and Malanotte-Rizzoli, 2010) might allow reptiles caught in debris on the streams to be carried to these islets.

Human-assisted dispersal, by hitchhiking, is a distinct possibility: fishermen and recreational swimmers frequently visit the islets (personal observation) and we observed plastic debris and fishing nets deposited on their shores. *H. turcicus* is well-known as a commensal species that occupies human establishments (Bar and Haimovitch, 2011; Werner, 2016), and *C. ocellatus* is suspected to have colonized new islands in the Mediterranean via human-assisted dispersal (Kornilios et al., 2010; Lymberakis and Poulakakis, 2010; Itescu et al., 2016).

Finally, there is the option of these being relictual populations from earlier geologic periods when islets were connected to the mainland, possibly as recently as ~4,000 years ago (Sneh and Klein, 1984; Sivan et al., 2001). We think this scenario may be especially likely for *A. boskianus*. The Israeli coastal populations of *A. boskianus* occupy loose, coastal sand dunes (Bar and Haimovitch, 2011; Werner, 2016), and are not known to be commensal. We only observed the species on two islets (Dor and Shehafit) which had sandy soils. In fact, the proposed biogeographic scenario of *A. boskianus* colonizing the Israeli coastal sands during periods of Pleistocene sea-level changes (Tamar et al., 2014) also lends itself to colonization of the islets before their detachment from the mainland.

Ultimately, these three possible mechanisms are not mutually exclusive, and may have all contributed to the formation of the islets' reptile assemblages. Estimating genetic divergence of the islet populations from nearby mainland populations may help elucidate their biogeographic origins.

In conclusion, we report here surprisingly rich reptile assemblages from such small, isolated landmasses. These findings may be of conservation concern as well — Israel's Mediterranean islets are all declared nature reserves, and on top of their importance as nesting sites for *Larus michahellis* and *Sterna hirundo*, the latter species red-listed in Israel (Mayrose et al., 2017), they also contain rich communities of reptiles, possibly from unique and isolated lineages. We encourage future research into these and similar islets, to further understand how such small patches of habitat can support vertebrate communities.

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