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Distribution, ecology, and conservation of *Philochortus zolii* in Mauritania: implications for the long-term persistence of an endangered lizard

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ABSTRACT

Philochortus zolii is a globally endangered lizard known only from five localities scattered across North Africa. The population is thought to be decreasing, but there are almost no data about this Sahara-Sahel endemic lizard. Recently, a sixth population was found in Mauritania, at the coastal peripheral zone of the Diawling National Park, which constitutes a remarkable opportunity to gather ecological information for the first time and to plan conservation actions. Here we assess the *P. zolii* regional distribution in Mauritania, estimate population abundance, analyse the species activity patterns, characterise the occupied habitats, assess local threats, evaluate the national conservation status, and define an action plan for the local conservation of the species. *P. zolii* is locally rare and exhibits a much-localised distribution, but additional sampling is needed in other humid areas to fill out the knowledge gap on global distribution. The activity period is very restricted, limited to the central hours of the day, with low detectability and high specialisation in habitat use. The species is evaluated as Critically Endangered at the national level and is threatened by industrial and agriculture developments. These activities have degraded the suitable available habitats and hamper any dispersal possibility. Extreme climatic events related with sea-level rise could decimate the entire Mauritanian population. Any pet trade that may be stimulated by the current discovery should be carefully supervised and monitored. The discovery of this isolated population justifies that coastal habitats should be designated as integral protection zone and included inside the Diawling National Park.

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Introduction

The remoteness of deserts and arid regions, and in some cases its long-term conflicts and socio-economic instability (Brito et al. 2014, 2018), along with the scarce scientific

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attention (Durant et al. 2014), contributes to the lack of information available for species diversity and distribution in these regions. Despite the increasing research efforts in the Sahara-Sahel over the past decades (Brito et al. 2014; Brito and Pleguezuelos 2019), the knowledge about the species diversity and their geographical distribution in the largest warm desert on Earth remains scarce (Brito et al. 2014, 2016). The available data on species diversity and distribution are still insufficient for the optimised identification of priority conservation areas that ensure the long-term representation and persistence of biodiversity (Brito et al. 2016). As such, the development of conservation measures is hampered by these knowledge gaps, which need to be carefully recognised, quantified, and reduced in order to make accurate decisions addressing the global biodiversity crisis.

Zolio's shield-backed ground lizard (*Philochortus zolii*, Scortecci, 1934) is a Sahara-Sahel endemic reptile, known from only five localities scattered between Mali and Egypt, with a total area of occupancy below 500 km^2 (Figure 1; Wagner et al. 2013). Overall, there is a huge lack of information about the biology of *P. zolii*. Studies conducted to the population in Egypt revealed very few information (Baha el Din 2006), and almost nothing is known from the populations in Mali, Niger, and Libya (Trape et al. 2012). The species is considered rare and listed as globally Endangered, with decreasing populations and suitable habitats (Wagner et al. 2013), and is one of the few North-African reptiles considered threatened by the International Union for Conservation of Nature, IUCN (https://www.iucnredlist.org/). *P. zolii* is found in semi-desert sandy areas with steppe vegetation, apparently linked with humid environments. The apparently high specification in habitat and the sampling gaps in the Sahara-Sahel region may led to its fragmented population structure (Trape et al. 2012; Wagner et al. 2013). The five known locations are all outside protected areas, which limit the implementation of conservation measures.

Remarkably, a specimen *P. zolii* was detected in February 2016, in the peripheral coastal zone of the Diawling National Park (DNP), Mauritania, approximately 1 500 km west of the westernmost known population (Figure 1). Later, in 2017, the specimen was genetically

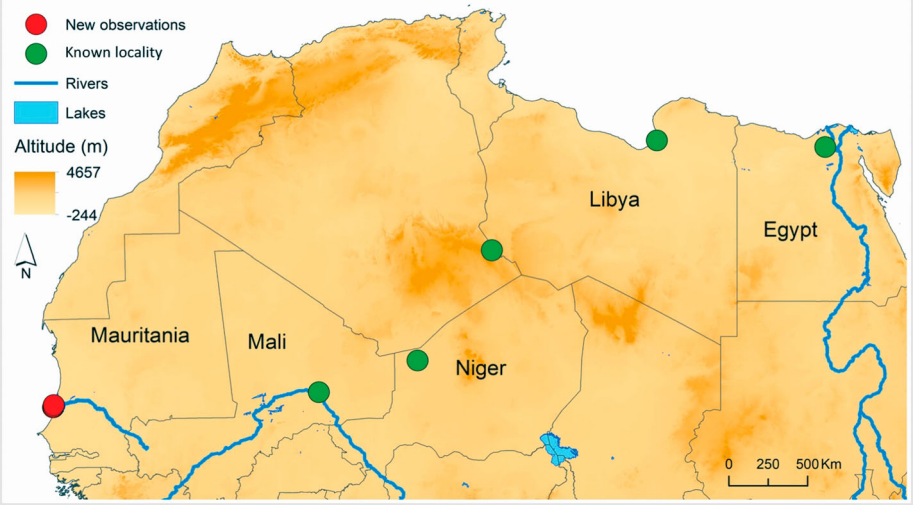

Figure 1. Known global distribution (green circles) of *Philochortus zolii* in North Africa (adapted from Wagner et al. 2013) and location of the new population (red circle) discovered in Mauritania.

confirmed as *P. zolii* (based on COI gene and using as reference a sample from the Egyptian population available through the BEV/CEFE collection; Velo-Antón et al. unpubl. data), establishing the first observation of this species in Mauritania and in all of West Africa. The population discovered in the DNP peripheral zone greatly enlarges the known range of this endangered species, but the population status is mostly unknown. In fact, despite the relatively detailed sampling of the DNP and surrounding areas between 2010 and 2016 for the development of the National Park Atlas of Amphibians and Reptiles (Sow et al. 2017), *P. zolii* remained undetected, a potential indicative of its rarity and difficult detectability. Indeed, fieldwork undertaken during three days in December 2019 to evaluate local population status, preliminarily revealed an extremely limited distribution (only four individuals observed) restricted to very specific coastal scrublands. Nevertheless, it is unclear whether the species is locally rare or if it exhibits low activity that hinders detectability, as all individuals were strictly observed at approximately 13h00 to 15h00, whereas sampling efforts were undertaken from morning to evening (Naia et al. 2019).

The discovery of a new location in coastal West Africa inside a Ramsar site and in the Transboundary Biosphere Reserve (TBR) of the Lower Senegal Delta (Diarra 1994), where regional security is ensured, constitutes a remarkable opportunity to gather detailed information for the first time on biological and ecological traits, and threat factors of this threatened species. Furthermore, it opens the possibility to define management actions for species protection that are likely feasible to implement inside a protected area. Here, we aim to answer the following questions: (1) Where is *P. zolii* distributed in the area of the DNP and which are the characteristics of its habitats?; (2) What is the population abundance?; (3) When is the species most active throughout the day?; (4) Which are the main threat risks to the conservation of the species? (5) What is the national conservation status? and (6) What actions can be developed for the conservation of the species in the DNP peripheral zone?

Materials and methods

Study area

The study area encompasses an area of 36 km^2, varying between 16.276° N to 16.577° N and 16.438° W to 16.516° W, in the peripheral coastal zone of the Diawling National Park (DNP), located along the Atlantic region of southern Mauritania, West Africa (Figure 2). This area is partially designated as Ramsar site and it is included in the TBR of the Lower Senegal Delta (Diarra 1994). The habitat is characterised by coastal scrublands with halfa grass (*Desmostachya bipinnata*), perennial bunchgrass (*Sporobolus spicatus*), small shrubs (*Tetraena gaetula waterlotii*), tall shrubs (*Maytenus senegalensis* and *Euphorbia balsamifera)* and two tree species (*Acacia karroo* and *Balanites aegyptiaca*). These natural habitats are disrupted by the mineral extraction of black sands initiated in 2016, and the associated industrial Ndiago Port, constructed in 2018 for their exportation, fisheries, and military activities.

Fieldwork

Field surveys were conducted in the DNP peripheral coastal zone during seven days in October–November 2020. In total, 30 visual encounter surveys, following linear transects,

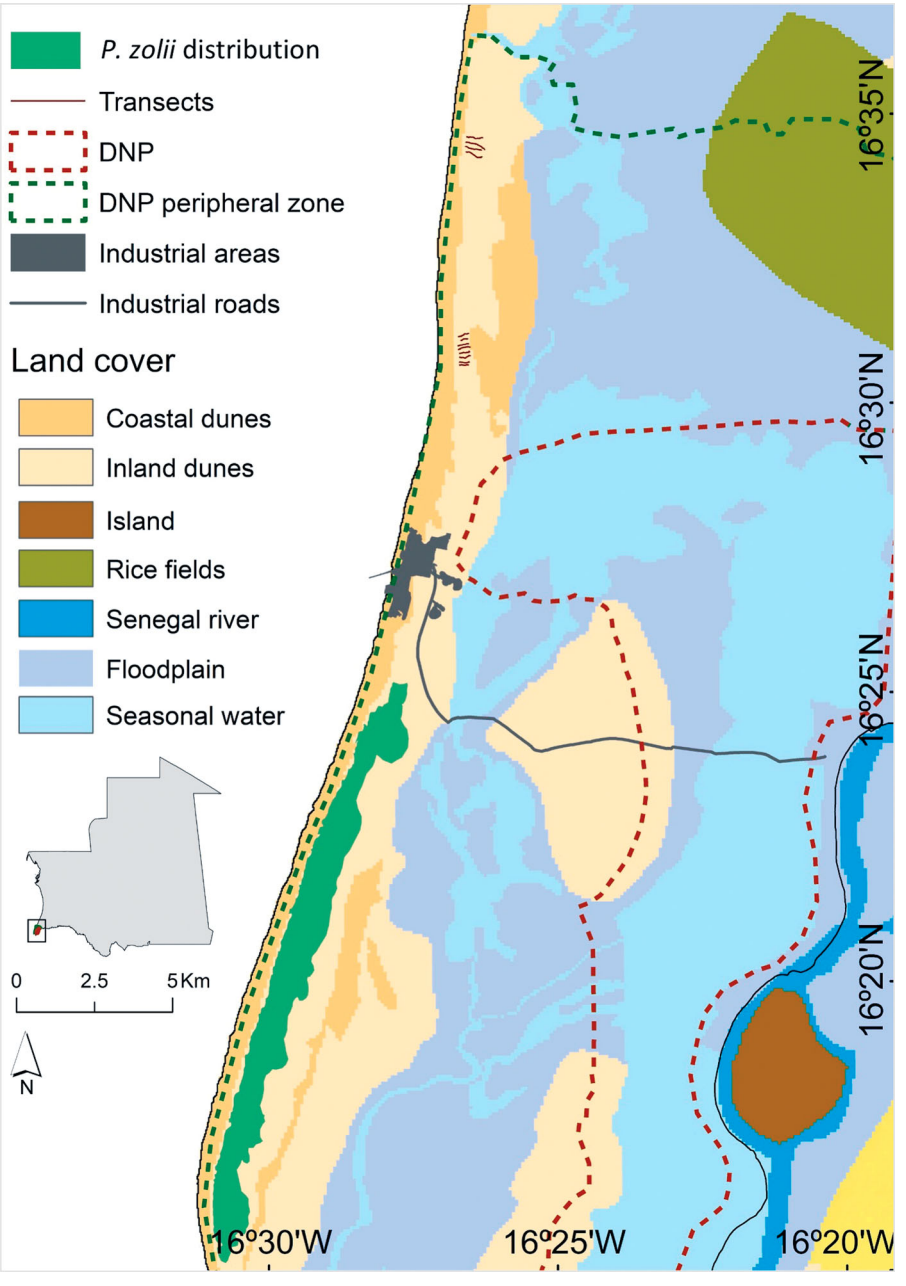

Figure 2. Location of the study area, in the peripheral coastal area of the Diawling National Park (DNP), transects performed and the observed distribution of *Philochortus zolii*.

were covered on foot by two persons walking parallel at three meters distance, covering a sampling width of six meters. Transects followed a west-east orientation, starting on the coastal dunes to the interior (Figure 2), and the sampling distance and time were recorded. A transect was considered finished when 1 000 m distance or 60 min of duration was reached, whichever was first, or when the habitat changed radically. The 30

transects distanced from 311 m up to 1 183 m long (average: 808 m) and lasted from 16 up to 60 min (average: 41 min). Sampling was concentrated between 08:30 and 16:27 and covered the central hours of the day to maximise the detection probability (Supplementary Table S1). Each individual of *P. zolii* was quantified using visual active search and a Global Position System (GPS) was used to record the location coordinates and the transect routes.

Abiotic and biotic variables were collected during the transects: competitor and predator species (*n*) were quantified by counting the number of potentially competitor and predator individuals per species using visual active search; temperature (°C) and relative humidity (%) were measured with a digital psychrometer at the beginning and end of each transect; cloud cover (%) was measured at the beginning and end of each transect with a A4 transparent sheet divided into 16 blocks; and wind speed was measured using the Beaufort scale. In 25 transects, the land cover (LC) structures were classified in four categories (bare soil, grasslands, scrublands, and dense vegetation), by collecting and georeferencing control points every 10 m to obtain the vegetation cover for each transect and determine the habitat selection of the species. The abiotic characteristics of each transect are described in Table S1.

Conservation status and threats risks

The national conservation status of *P. zolii* was evaluated in RAMAS Red List v. 2.0 (Akçakaya and Ferson 2001), following the methodology and criteria of the IUCN Red List guidelines for the application and regional and national levels (IUCN 2012). The parameters for categorisation were the population reduction inferred from the decline in the available of suitable habitat, population fragmentation, number of locations, and the geographic range. The former parameter was based on the extent of occurrence (EOO), using the minimum convex polygon (Figure 2) to capture the known geographic range of *P. zolii*, and the area of occupancy (AOO), using a 2 km^2 grid cell, to calculate the total area of all grid cells with species observations. The calculations were performed using the geometry calculator tool in ArcGIS (ESRI 2016) based in a projected coordinate system (WGS84 UTM zone 28N).

Local threats were identified and quantified in the field and georeferenced from Google Earth when appropriate (e.g. industrial activities). Finally, the integration of all results was used to derive an action plan for the conservation of *P. zolii* in the DNP peripheral zone, delineating the conservation activities needed to be implemented to decrease the extinction risk of *P. zolii* in Mauritania, and consequently, in all West Africa.

Statistical analysis

The abundance of *P. zolii* and its competitors in each transect was standardised using a Kilometric Abundance Index (KAI; Thompson et al. 1998), by dividing the number of individuals observed in each transect by the total length of that transect (km). The average values and standard deviation of each environmental variable collected in the field, at the beginning and end of each transect, were calculated. The frequencies of each land cover category in the 25 transects from where habitat data were available, were compared between areas where *P. zolii* was detected against the ones where the species

was not detected to evaluate the habitat selection. Differences in proportions were analysed by Kruskal–Wallis χ^2 tests and correlation analyses as appropriate (Siegel and Castellan 1988). A minimum rejection level of $\alpha = 0.05$ was used in all statistical tests.

Results

Distribution and abundance of P. zolii

In total, eight individuals of *P. zolii* were observed, one of which was a juvenile (Supplementary Figure S1). The species was detected in five transects (from one up to three individuals) and the average KAI was 1.66, ranging from 0.93 to 3.00 (Figure 3).

Taking together the observations made in 2019 (Naia et al. 2019) and the ones in the current work, *P. zolii* is currently known to inhabit a single narrow band (up to 1.5 km wide) along the coast, extending 20 km long in the DNP peripheral zone south of the Ndiago Port (Figure 2).

Activity patterns

There were significant differences in the daily activity patterns of *P. zolii* and in five other lizard species found in sympatry or parapatry in the study area ($\chi^2 = 54.24$, DF = 18, $p < 0.001$). *Philochortus zolii* displayed restricted activity, as all individuals were strictly observed from 12h00 to 14h00, when the air temperature was highest and relative humidity reached the lowest values (Figure 3). The other five reptile species displayed distinct activity peaks during the day: along the morning in *Acanthodactylus dumerilii* and *Agama boueti*, by midmorning in *Latastia longicaudata* and *Trachylepis perrotetii*, or in the afternoon in *Acanthodactylus boskianus*.

Significant correlations were detected between the number of *P. zolii* observed and increasing air temperature, decreasing relative humidity, and slower sampling speeds

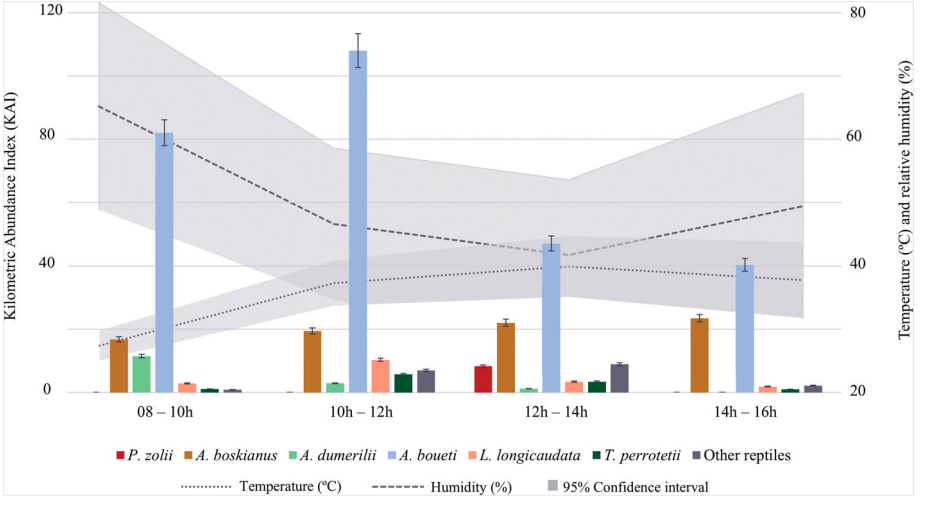

Figure 3. Abundance and daily activity patterns of the lacertid community, and respective environmental variation, in the peripheral coastal area of the Diawling National Park (DNP).

(Table 1), suggesting that the species is more active during the warmer periods of the day and that its detection requires very slow walking speeds. Other strong positive significant correlations included the number of *A. boueti* and *A. boskianus* observed and the duration and length of the transects, suggesting that they are very common species, and a negative relationship with hour of the day in *A. boueti* suggesting that the species is mostly active during the early hours of the day.

Potential predators of *P. zolii* detected in the transects, included the snake *Psammophis* sp. and three bird species (*Coracias garrulus*, *Myrmecocichla aethiops*, *Upupa epops*), as these species are known to predate small lizards. The majority of these observations were made during the morning periods, with the exception of two bird individuals (*C. garrulus*, *U. epops*) that were observed between 14h00 and 16h00.

Habitat selection

According to the full set of *P. zolii* observations available, we surmised that the species was present south of Ndiago Port and absent in the areas north of this infrastructure. There were significant differences (Kruskal–Wallis $\chi^2 = 261.40$, DF = 3, $p < 0.001$) in the frequencies of the land cover categories in the 18 and seven transects performed in the presence and absence zones, respectively. The transects performed in areas classified as of *P. zolii* presence were characterised by denser vegetation of *Euphorbia balsamifera* and *Acacia karroo* (30.7%), interspersed with bare areas (44.4%), and some small shrubs, *Tetraena gaetula waterlotii*, (13.2%), whereas the transects performed in areas classified as of absence were characterised by lesser areas of dense vegetation and bare areas (13.1% and 13.9%, respectively), and with great abundance of grasslands of *Sporobolus spicatus* and *Desmostachya bipinnata* (53.5%) and shrubs (19.6%).

Conservation status and threats risks

The natural habitats of the central zone of the study area have been heavily destroyed by the opening of the Ndiago Port in 2018, with associated new roads to provide accessibility to the industrial area (Figure 2). Surrounding the port, the mining activities starting after 2016 for the prospection and extraction of black sands also changed radically the landscape and further destroyed natural habitats (Supplementary Figure S2). In addition, both central and northern habitats of the study area have been also modified by the

Table 1. Correlation coefficients between number of observed individuals and abiotic variables in 30 sampled transects: starting hour (Hour), mean temperature (Temp), mean relative humidity (Hum), duration of sampling (Duration), length of the transect (Length), and walking speed (Speed). Statistical significance: $*p < 0.05$, $**p < 0.001$.

Species	Hour	Temp	Hum	Duration	Length	Speed
P. zolii	0.08	0.41**	−0.32*	0.18	0.24	−0.30*
A. boskianus	−0.06	0.12	−0.25*	0.63**	0.56**	−0.32*
A. dumerilii	−0.25*	−0.01	0.08	−0.21	−0.17	0.16
A. boueti	−0.47**	−0.27*	−0.15	0.45**	0.42**	−0.14
L. longicaudata	−0.23	−0.17	0.09	0.07	0.04	−0.03
T. perrotetii	−0.06	0.15	−0.08	0.06	−0.07	−0.21
Other reptiles	0.06	0.07	−0.19	0.31*	0.35*	−0.13

installation of agriculture fields. The intense human activities from the central part northwards, also suggest that the single suitable habitats for *P. zolii* are found exclusively south of Ndiago Port (Figure 2). These habitats are found in high proximity to the ocean (<1 km), therefore sea-level rise and consequent stochastic events, such as storms and floods, can threatened the single Mauritanian location.

Philochortus zolii was classified as CR-Critically Endangered B1ab (i, ii, iii, v), relying on the geographic range (criterion B), with an estimated EOO of 18.58 km^2 and an AOO of 14 km^2, the severely fragmented character of the population, and on the continuous decline of suitable habitat. The category attributed was not downlisted, given the absence of other neighbouring population that could provide migrating individuals into the studied population (decreasing the extinction risk within the region).

A list of actions for the conservation of *P. zolii* in the peripheral zone of the DNP was delineated, considering the current threats to the species that require different priorities and time-scales for implementation (Table 2).

Discussion

The finding of a new population of *P. zolii* in West Africa greatly enlarged the known global distribution of this threatened species, which represents an important step to increase the limited knowledge on its distribution. As a result of the discovery of this new population, the DNP harbours now 27 reptile species, which represents about 25% of the total reptiles known from Mauritania (Sow et al. 2017).

Philochortus zolii in Mauritania

Philochortus zolii was found in an area with high humidity levels (Figure 3), in relation to other regions of Mauritania, which is in line with the reported humid conditions of other localities where the species was detected across the Sahara-Sahel (Trape et al. 2012). Given the trend to occupy humid habitats, the species could be present in

Table 2. List of recommended actions for the conservation of *P. zolii* in the peripheral zone of the Diawling National Park, Mauritania.

	Short-term actions	Long-term actions
High priority	Promote habitat management:	Increase legal protection:
	Limit off-road vehicle circulation to avoid road-killing mortality.	Provide information to stakeholders on the ecology, threats, and management requirements.
	Prevent changes in land use, such as expansion of agricultural and pastoral activities in important areas for the species.	Legally protect the locality under national legislation, for instance the inclusion in the National Park.
	Prohibit the southward expansion of industrial activities.	
Low priority	Increase public awareness:	Counteract sea-level rise effects:
	Promote *P. zolii* as flagship species for the conservation of coastal areas of the DNP.	Develop management actions in the coast, such as dune restoration and building living shorelines
	Implement awareness-raising campaigns targeted at various interest groups, such as farmers, schools, and DNP inhabitants.	Continue the mangrove restoration in the DNP.

other humid Mauritanian environments, such as the coastal area north of the DNP up to the capital (Nouakchott) and the southern riparian habitats along the Senegal River margins. Surveys of these areas have proven unfruitful so far: 1) the coastal area north of Ndiago Port up to Chott Boul (Figure 2) was sampled for two days in the current study and also in multiple occasions between 2010 and 2016 (Sow et al. 2017); 2) the coastal area north of Chott Boul up to Nouakchott was sampled during the 1990s (Colas 1997); and 3) the humid habitats along the Senegal river were periodically sampled from 2010 to 2020 (Brito et al. unpubl. data). However, given that *P. zolii* is locally rare, displays low detectability, and exhibits a very short activity period, increasing sampling efforts in the humid areas of Mauritania and the Sahara-Sahel is needed to possibly disclosure new populations and fill out current distribution gaps.

Philochortus zolii was observed exclusively in the central hours of the day, 12h00 to 14h00, during the daily periods of highest air temperature and lowest humidity. This activity pattern was observed in the dry season, during the current study, October and November, as well as in the previous preliminary survey, in December (Naia et al. 2019). However, *P. zolii* might be active earlier, for instance thermoregulating protected by the vegetation, which limits its detectability. Furthermore, it remains to be determined if during other times of the year, for instance during the mating season, the daily activity period is more extended, as generally observed in most reptile species (Vitt and Caldwell 2014). The activity patterns of *P. zolii* contrasted with the activity displayed by other lacertid species found in the study area, as the later were more active during the morning (Figure 3). The restricted activity of *P. zolii* and concentrated in the central hours of the day might be a strategy to minimise interspecific competition with other similar body-sized reptiles and/or avian predation. Another variable that can be considered in future studies is prey abundance. Determining which prey are active in the different time periods of the day might help understanding *P. zolii* diet, as well as understand its activity patters. The DNP offers suitable conditions for 124 species of migratory and resident birds of both Palearctic and Afro-tropic origin (BirdLife International 2020), and many may predate lizards. Still, potential avian or snake predators were not detected during the transects when *P. zolii* was observed. The ecological implications of such restricted activity pattern require further study.

The habitats occupied by *P. zolii* in the DNP peripheral zone are relatively well circumscribed; the interior sandy areas between the coastal dunes and the eastern floodplains, covered by stands of *Acacia karroo* and *Euphorbia balsamifera* (see photography in Supplementary Table S1), confirming that *P. zolii* is highly specialised in habitat selection. Previous field observations in Egypt noted that *P. zolii* searches for refuge under the vegetation and uses graminoids to move (Baha el Din 2006), therefore land-cover type may potentially be related with population abundance. Although in other populations, *P. zolii* was observed in areas with higher density of grasslands (Baha el Din 2006; Trape et al. 2012; Wagner et al. 2013), in the DNP peripheral zone most individuals were detected on small bushes and in small stands of *Acacia karroo* tree, and also in open fields, possibly moving from one bush to the other. Still, the species tends to dwell almost exclusively on top of vegetation, only rarely reaching the soil level.

Conservation implications and future directions

The distribution of *P. zolii* in the DNP peripheral zone is very limited, either by natural reasons, such as the Atlantic Ocean to the west, the floodplains and estuary of the Senegal River to the east and south, or by human activities to the north. In fact, the construction of the Ndiago Port and the concessions for the exploitation of black sands on the northern limit of the area from where *P. zolii* is currently known has seriously degraded the available habitats. Furthermore, agriculture is increasing in this area and *P. zolii* might not be able to adapt to cultivated land (Wagner et al. 2013). These factors threaten the lizard population and contribute to its extreme isolation character, turning almost impossible the successful dispersal and gene flow from any hypothetical populations located to the north or north-east of the known population.

Sea-level rise poses an additional threat to this population, due to its proximity to the ocean and the low altitude of the study area (299–734 cm; average: 468 cm; estimated from Kulp et al. 2018). Since *P. zolii* is only present in one location, a single extreme event related with climate change and sea-level rise could easily affect all individuals of this population (IUCN 2012). The DNP was identified as one of the 15 topmost African coastal protected areas with high international conservation relevance and importance for biodiversity conservation and high exposure to sea-level rise (Brito and Naia 2020). As such, local adaptive measures are urgently in need of development to cope with the negative consequences of sea-level rise.

Given that *P. zolii* is a rare and charismatic species, the disclosure of the new location may stimulate the use of biological resources. Direct persecution of individuals for collection (pet trade) can affect the isolated population of *P. zolii* at the DNP peripheral zone, as is happening in Egypt (Baha el Din 2006). For this reason, precise locations of the species are not given in the current study, but the authors will share them on request.

In the long-term, the Ministry of the Environment of Mauritania should thoroughly consider the westwards expansion of the Diawling National Park to include the coastal habitats where *P. zolii* is known to occur. The reasons for such expansion include the national and global relevance of the conservation status of the species, and the observed continuing decline in the availability of suitable habitats. Furthermore, the area is currently designated as a Ramsar site and it is included in the Transboundary Biosphere Reserve of the Lower Senegal Delta. Including the coastal habitats in the DNP area and designating them as an integral protection zone would provide protection against any potential southward expansion plan for the current industrial area, which would in turn prove fatal for the lizard population.

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SUPPLEMENTARY MATERIAL

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Distribution and ecology of *Philochortus zolii* in Mauritania: conservation implications and future directions

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Table S1. Characteristics of the 30 transects: transect code (Transect), date in 2020 (Date), starting hour (Hour), mean temperature (Temp), mean relative humidity (Hum), cloud cover (Cloud), wind speed (Wind, from null [0] up to very strong [4]), duration of sampling (Duration), area sampled (Area), and an illustrative photography of the sampled habitat (Photo).

Transect	Date	Hour (h:m)	Temp (ºC)	Hum (%)	Cloud (%)	Wind	Duration (min)	Area (m^2)	Photo
T1	26/10	11:48	39.7	30.0	0	1	41	5082	
T2	26/10	15:37	41.1	21.0	0	2	60	5790	
T3	27/10	08:45	31.3	46.0	0	0	60	5610	
T4	27/10	10:43	39.7	37.5	0	2	60	6264	

T5	27/10	13:19	35.0	39.0	0	3	53	6438	
T6	27/10	15:20	31.7	50.5	0	3	47	6942	
T7	28/10	08:31	28.9	43.5	0	0	57	6264	
T8	28/10	10:29	34.5	32.5	0	1	49	5970	
T9	28/10	12:15	38.8	26.0	0	1	48	6210	

T10	28/10	14:27	39.1	26.0	0	1	44	6378	
T11	29/10	08:36	29.9	30.0	0	1	60	6444	
T12	29/10	10:26	34.9	31.5	0	2	45	6174	
T13	29/10	12:23	39.3	28.0	0	3	45	6000	
T14	29/10	14:32	35.4	41.0	0	3	31	4284	

T15	30/10	08:30	27.5	41.5	30	3	60	7098	
T16	30/10	10:46	32.6	35.5	0	3	49	6252	
T17	30/10	12:51	31.0	43.0	0	4	57	5748	
T18	30/10	14:58	30.3	48.5	0	4	37	4860	
T19	31/10	08:40	27.2	68.5	0	4	23	2352	
T20	31/10	09:22	31.1	56.0	0	4	18	2088	Not available

T21	31/10	10:41	31.1	55.0	0	4	25	2844	
T22	31/10	11:27	33.3	49.0	5	3	25	2724	
T23	31/10	12:36	31.8	48.5	0	3	32	3660	
T24	31/10	13:36	31.0	49.5	0	3	24	2424	
T25	31/10	15:14	29.3	56.5	0	3	16	1866	
T26	31/10	15:47	29.5	56.0	0	3	23	3258	Not available

T27	01/11	08:35	27.1	57.0	0	0	30	3870	
T28	01/11	10:30	33.5	33.0	0	1	31	3906	
T29	01/11	12:02	38.2	28.5	0	2	39	4872	
T30	01/11	14:01	39.3	25.5	0	2	28	3756	

Figure S1. *Philochortus zolii* in the peripheral coastal zone of Diawling National Park, Mauritania. Photos by Marisa Naia.

Figure S2. Degraded habitat surrounding the Ndiago Port due to its construction and the prospection and exploitation of black sands. Photos by Marisa Naia.