Monitoring herpetofauna and chiropterofauna on Santiago and Sal windfarms

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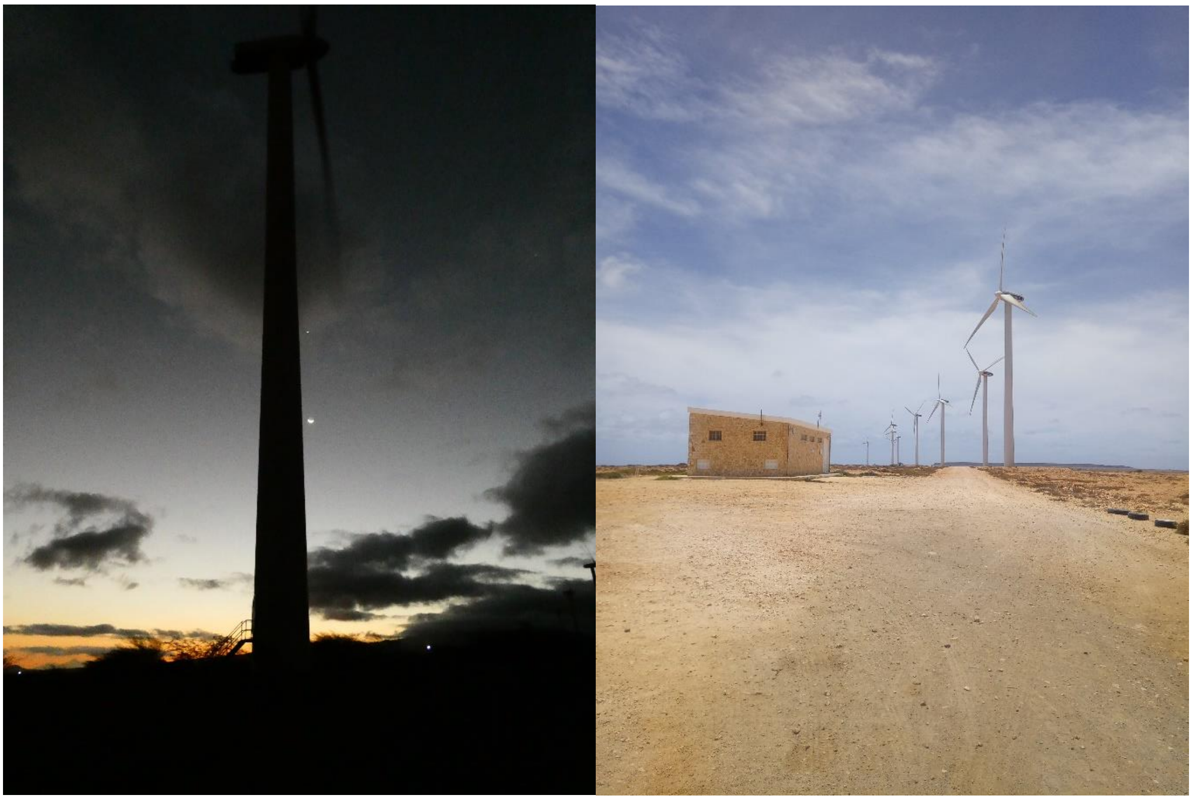

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Introduction

According to Environmental and Social Standards of the European Investment Bank the protecting and conserving biodiversity and ecosystems and maintaining the ecological functions and processes of such ecosystems is important to achieve environmental and social sustainability (European Investment Bank 2022). Thus, to halt and reverse biodiversity loss, increase biodiversity and ecosystem benefits it is needed to identify, assess, manage and monitor the impacts and risks affecting biodiversity and ecosystems from any project development. Threat assessment shall also, for example, include loss, degradation and fragmentation of habitats, loss of species diversity and abundance, loss of genetic diversity, degradation of ecosystem services, as well as project-related climate change impacts (European Investment Bank 2022). For that, establishing a baseline of the biodiversity features and their threats with field surveys in different seasons in the project area before the project development, including climate change impacts and risks is mandatory. Considerations about appropriate measures required to adapt to climate change should also be assessed (European Investment Bank 2022).

Reptiles represent the most diverse group of terrestrial vertebrates in the world with circa 12 000 species (Uetz et al. 2023) and are a major component of the global biodiversity, remarkable from an ecological and evolutionary point of view. Unlike other vertebrates, reptiles are ectotherms, and are greatly affected by the thermal landscapes of their habitat, and thus good indicators for climate change studies (Carretero et al. 2016). Moreover, they are relatively easy to catch and sample for biodiversity surveys, although detailed information on their distribution ranges and ecology may be lacking. In Cabo Verde there are 23 native species of reptiles, all of them endemic of the archipelago and some single-island endemics (Vasconcelos et al. 2013).

Bats are the only mammal group capable of sustained flight and the second most diverse mammal group worldwide, with approximately 1 400 species. They are recognized as one of the most affected groups by wind farms worldwide (Peste et al. 2015). This diverse mammal group is known for delivering several ecosystem services, e.g., pest control (Mata et al. 2021), but the current knowledge of bats at Cabo Verde is still very limited (Vasconcelos 2018, Borloti et al. 2020).

Following the recommendation of the World Bank Group, surveys should be targeted to species of flora and fauna of high biodiversity value, such as taxa classified as threatened at national and international level, and endemic taxa. In fact, all Cabo Verde native reptiles are endemic and around half of them are threatened of extinction (Vasconcelos et al. 2013). Those same recommendations are highlighted targeting taxa that are at elevated risk of impact from wind energy facilities. And in this case, bats are possibly affected by this threat. Bats are known to be affected by wind farms around the world, not only indirectly through habitat loss but also directly through collision with wind blades (as birds) and barotrauma. Barotrauma is a significant mortality factor for bats at wind farms, because their internal organs are sensible to differences in air pressure caused by the rotation of the wind blades, damaging their tissues, even when there is no direct contact with the rotation blades (Peste et al. 2015). In North America, up to 70 bats per year can be killed by each turbine, with the highest estimates in Europe being a little lower (up to 41). However, mortality rates are highly site-dependent and particularly linked with low wind speeds (< 4.5m/ s). In Cabo Verde, it is still unknown if any of the five recorded bat species is endemic, although some seem to be native (Borloti et al. 2020).

Objectives

The goals of this study are to:

i) identify the main threats affecting the target taxa and their habitat;

ii) identify which reptile and bat taxa occur in each windfarm study area;

iii) establish a baseline for genetic and species diversity of the target reptile and bat taxa;

iv) compare these indicators with control areas outside the windmill areas;

v) list habitat restoration and management actions for the reptile/bat communities.

Study area

On Santiago, the windfarm area, located in the south of the island within Praia district, coincides with the known distribution area for four to six endemic reptile species (Vasconcelos et al. 2013). More specifically, there is a high probability of occurrence for the Data Deficient Santiago wall gecko *Tarentola rudis*, Darwin's wall gecko *Tarentola darwini*, Delalande' skink *Chioninia delalandii*, Santiago skink *Chioninia spinalis santiagoensis.* The latter three taxa are classified as Least Concern. The occurrence of the Critically Endangered Bouvier's leaf-toad gecko *Hemidactylus bouvieri* was cited in the last century for the southern of Santiago, but no individuals were found so far (Vasconcelos et al. 2013). All of these reptiles are not only endemic to the country, but also taxa only occurring on Santiago Island, except *C. delalandii*.

Even though the windfarm seems to fall outside the area of higher probability of occurrence of the Vaillant' skink of Santiago *Chioninia vaillantii vaillantii*, its presence should be checked as it is in the border of its potential area of distribution. In addition, this is a species classified as Endangered and a taxon only occurring on Santiago (island endemic) with a decreasing populational trend (Vasconcelos 2013a), thus the surrounding areas should be also monitored.

On Santiago there are records of three bat species, *Taphozous nudiventris*, *Plecotus austriacus* and *Pipistrellus* cf. *kuhli*. All have very few records (Vasconcelos 2018). However, targeted surveys for bat species were performed very sporadically in the archipelago and need to be reinforced (Borloti et al. 2020). Feeding or roosting bat habitats, both within the windfarm area and in its vicinity, may exist and thus the surrounding areas should be also monitored.

On Sal, the windfarm area is located in the middle eastern part of the island. This area coincides with the distribution of Sal skink *Chioninia spinalis salensis*, a Near Threatened taxon unique to this island (Vasconcelos 2013b, Vasconcelos et al. 2013). There is low probability of occurrence of the Sal leaf-toed gecko *Hemidactylus boavistensis chevalieri* in the area, but as this is also an island endemic, probably threatened, it is important to confirm this and to check the surrounding areas. An unknown probably vagrant Molossidae bat was seen in the south of the island, in Ponta Preta in 2014, but no other record was registered (Vasconcelos 2018); however, as referred before, this may be due to a lack of sampling (Borloti et al. 2020).

Sample sites

Santiago windfarm is located at 14.97035º N, 23.51461º W at circa 265 m above sea level (asl) and has an irregular shape with approximately 1x2 km of maximum length and width, respectively. It was divided in 10 plots and three transects were visited for the herpetological and chiropterogical surveys, respectively. A similar area, with similar habitat, size and elevation, nearby the windfarm located near the National Stadium at 14.98725ºN, 23.53353ºW was used as control where three transects were performed.

Sal windfarm is located 16.70209º N, 22.90129º W at circa 60 m asl and has a rectangular shape with approximately 1,5x0,3 km. It was divided in 5 plots and two transects that were visited for the herpetological and chiropterogical surveys, respectively. A similar area, with similar habitat, size and elevation, nearby the windfarm located near the airport at 16.69812ºN, 22.90097ºW was used as control where two transects were performed.

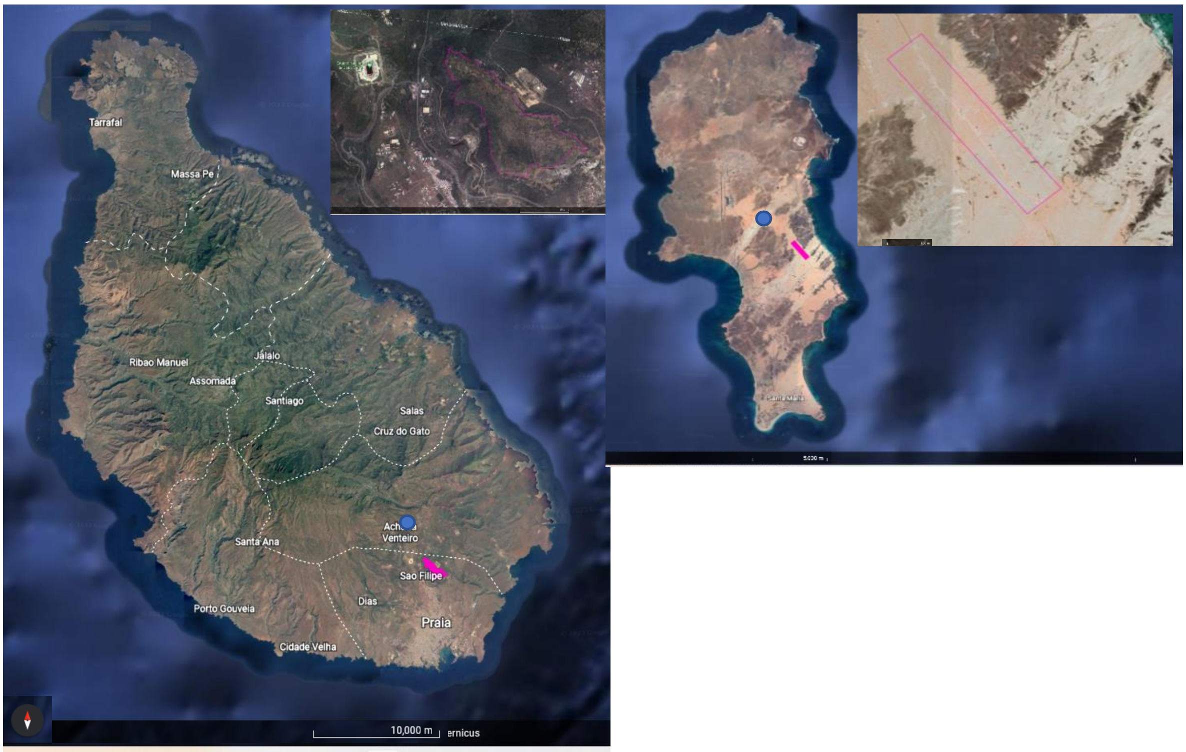


Fig. 1 Study area and study sites. **A)** Santiago and **B)** Sal windfarms locations are marked in pink and zoomed in the top left of each image, and the control areas in blue (google earth).

Sampling strategy

The team was composed by experienced biologists with training in environmental surveys (e.g., Vasconcelos et al. 2009, 2011, 2016, Peste et al. 2015).

For the herpetofauna survey, a total of two experienced herpetologists were in charge of the field surveys. In the first trip, the team was composed by the team leader, Raquel Vasconcelos, a PhD world expert in the Cabo Verde herpetofauna, and a Cabo Verdean PhD student hosted by CIBIO and the Technical University of the Atlantic (UTA) with expertise in field assistance, Lara Almeida. In the second trip, the team will be composed by Raquel Vasconcelos and Luís P. da Silva, a PhD expert in environmental impact studies on vertebrates. For the chiropterogical survey, Raquel Vasconcelos was advised in the first trip and accompanied in the second trip by Luis P. da Silva, with expertise in ultrasound record collection and analyses, and accompanied by the PhD student in the first trip.

The sampling periods of reptiles occurred mainly in the dry season (early April), and of bats mainly immediately after the rainy season for 10 days each (October). However, a preliminary bat survey was performed in April as the team members are experienced in sampling both vertebrate groups. The confirmation of the reptile species occurring in both islands was performed after the rainy season as well.

Methods

General information

One of the key aspects of the assessment of both fauna sampling is that we carried out a complete detailed study of the area. It is important to take into account that reptiles include both nocturnal and diurnal species. In addition, the majority of bat species exhibit their highest levels of activity following sunset and during the initial hours of the night. As a result, we have adapted the surveys to the activity period of the different species to collect representative data on the whole herpetological and bat community, sampling both day and night periods.

Every day, the researchers sampled some plots of the sampling area. It is important to note that the researchers were highly trained in the use of all the necessary equipment for searching and handling the different reptile species and for recording bat sounds. The complete survey of both windfarms took place in the dry season between the 18 and 26 of April 2023 and after the rainy season between the 12 and 20 of October 2023. Sampling outside the peak of the dry season in April was important as reptiles reduce their activity in those periods (Vasconcelos et al. 2012). As the rainy season heavily reduces the activity of bats and reptiles, and also bat detectors have poorer detection ability in humid environments, we performed the second sampling after the end of the rainy season.

In the two missions, the team searched 15 plots and 5x2 transepts (2 in Sal and 3 in Santiago) and sampling was carried out during the day and the night period. Transepts were replicated in the control areas (please check **Table 1** for details). Therefore, each subarea was visited at the highest activity periods for reptiles and bats in April and was repeated after the rains in October. This strengthened the results of the surveys and allowed us to see differences in diversity and abundance between these two daily periods and areas (windfarm versus control).

Herpetological survey

For the herpetological fauna, surveys in April consisted of active searches within each plot. Active searches during the day included checking under stones and other possible refuges such as bushes, trees, rocks, boulders, caves, holes. The researchers made sure that by the end of the survey the whole area of both windfarms was thoroughly searched for diurnal reptiles. Nocturnal searches included mainly visual searching of active reptiles using flashlights and headlamps along transects. GPS records of every animal give us an idea of the taxa distributions within the windfarms and control areas.

For every specimen, we have assigned a code for databasing and record the specific GPS locality and time together with climatic data and several characteristics of the macro and the microniche where the animal was observed. We used field sheets specifically designed for Cabo Verde reptiles that have been thoroughly tested in other similar studies. Detailed photographs of the habitat and the animal (when possible) were taken using digital cameras.

When necessary, detailed morphological analyses of the specimens were carried out and, to untangle possible morphologically cryptic species, a tissue sample of all individuals was taken for a definitive identification in the laboratory and to cover intraspecific genetic diversity studies using molecular analyses of at least five specimens per taxon inside and outside the windfarms. The codes used for spatial, morphological, and molecular data were inserted into a comprehensive database assembled with all the data for posterior analyses. Morphological measurements were immediately taken after collection to avoid recording the same specimen twice during the survey. All precautions were taken to minimize the stress on the animals during this study.

After the rains, the survey was repeated using transects only, to confirm the species lists.

Chiropterogical survey

Bat surveys were performed mainly after the rains using activity surveys (transects) with a hand-held ultrasound bat detector. Activity surveys in April were performed at turbine locations and control areas with similar landscape and habitat conditions using the same transects for the reptile survey. The control areas allowed to evaluate the potential effect of the wind farm on bat diversity and activity patterns. A similar effort was done at wind farms and control areas, with three transects at Santiago wind farm and three in the surroundings (control area) and two at Sal wind farm (due to its smaller size) and two in the surroundings. Each transect lasted 15 to 30 minutes and was done by walking slowly (circa 2km/ h), to minimize noise and animal disturbance, resulting in approximately 500 m-transects (**Table 1**).

Transects on Santiago started 45 min after sunset and lasted for a maximum of 1 hour, corresponding to the period of highest bat activity. Surveys were made on nights with favourable weather conditions for bats, i.e., without rain, weak or no wind, mild temperature, and low humidity. On Sal, shorter samplings were performed in the activity peak starting 15 min before sunset to get preliminary data on the bat species and confirm their absence.

Transects were performed after the rains for 15 min on both wind farm locations, and the order in which transects were performed was changed between days, i.e., one night transects started at the wind farm, and in the next sampling night they started at the control areas, this way accounting for possible temporal variations.

We compared the sound records with the ones recorded in Cabo Verde previously and published by the team (Vasconcelos 2018). In October, surveys for potential mortality impact and bat roosts were performed. Mortality surveys were conducted at all windmills, encompassing the entire area around the tower within an approximate radius of 20 meters from the blade extension. Roost surveys were conducted around the wind farms and in other areas identified by interviewed locals as locations where bats were observed. Bat presence was checked by the presence of guano or seen/ recorded individuals. Guano and tissue samples (in the case of dead animals) were collected for genetic analyses to confirm taxonomic identity and monitor intraspecific genetic diversity. All possible roosts and vouchers were registered and GPS located and, if bats were present, their species and numbers. If a roost was found but it was not possible to see the animals, an acoustic survey was performed, starting 15 min before the sunset and with one hour of duration, to ensure that any bat was leaving the roost and recorded. All possible bat sounds were recorded and identified by sound analysis following Borloti et al. (2020).

Table 1. Details of the performed transects. The station (ST, Santiago, S, Sal, W windfarm, C, control area), date, number of observers (N), island, time (t) and coordinates (latitude and longitude in decimal degrees) of start and end of each transect are given.

ST	Date	N	Start t	End t	Island	Locality	Start Latitude	Start Longitude	End Latitude	End Longitude
STW1	18/04/2023	2	18:45	19:43	Santiago	São Filipe	14.96745	-23.51195	14.96949	-23.50845
STW1	18/04/2023	2	19:43	20:20	Santiago	São Filipe	14.96949	-23.50845	14.96745	-23.51195
SC2	19/04/2023	2	12:40	14:00	Sal	Espargos	16.72459	-22.92790	16.72401	-22.92281
SW1	19/04/2023	2	15:40	17:00	Sal	Murdeira	16.69595	-22.89691	16.69812	-22.90097
SW2	19/04/2023	2	18:00	18:40	Sal	Murdeira	16.70755	-22.90510	16.70305	-22.90339
SW1	19/04/2023	2	19:50	20:35	Sal	Murdeira	16.69812	-22.90097	16.69595	-22.89691
SC2	20/04/2023	2	10:40	13:00	Sal	Espargos	16.72035	-22.91408	16.72355	-22.91771
SC1	20/04/2023	2	20:00	20:45	Sal	Espargos	16.72459	-22.92790	16.72401	-22.92281
SC2	20/04/2023	2	22:30	23:00	Sal	Espargos	16.72355	-22.91771	16.72035	-22.91408
SW2	20/04/2023	2	23:20	00:00	Sal	Murdeira	16.72355	-22.91771	16.72035	-22.91408
STW1	22/04/2023	2	15:08	17:58	Santiago	São Filipe	14.96745	-23.51195	14.96949	-23.50845
STW2	22/04/2023	2	18:47	19:40	Santiago	São Filipe	14.97378	-23.51584	14.97070	-23.51260
STW2	22/04/2023	2	20:30	21:30	Santiago	São Filipe	14.97378	-23.51584	14.97070	-23.51260
STW2	23/04/2023	2	13:00	15:30	Santiago	São Filipe	14.97378	-23.51584	14.97070	-23.51260
STW3	23/04/2023	2	19:00	19:40	Santiago	São Filipe	14.97698	-23.52049	14.97437	-23.51662
STW3	23/04/2023	2	23:35	00:40	Santiago	São Filipe	14.97698	-23.52049	14.97437	-23.51662
STW3	24/04/2023	2	12:00	14:10	Santiago	São Filipe	14.97698	-23.52049	14.97437	-23.51662
STC1	24/04/2023	2	16:40	18:30	Santiago	São Filipe	14.98595	-23.53412	14.98147	-23.53485
STC1	24/04/2023	2	19:10	19:45	Santiago	São Filipe	14.98595	-23.53412	14.98147	-23.53485
STC1	24/04/2023	2	19:45	20:15	Santiago	São Filipe	14.98147	-23.53485	14.98595	-23.53412
STC2	25/04/2023	3	10:45	13:15	Santiago	São Filipe	14.98725	-23.53353	14.98530	-23.52904
STC3	25/04/2023	3	16:25	18:00	Santiago	São Filipe	14.99201	-23.52476	14.98790	-23.52473
STC3	25/04/2023	3	19:00	19:50	Santiago	São Filipe	14.99201	-23.52476	14.98790	-23.52473
STC3	25/04/2023	3	19:50	20:20	Santiago	São Filipe	14.98790	-23.52473	14.99201	-23.52476

ST	Date	N	Start t	End t	Island	Locality	Start Latitude	Start Longitude	End Latitude	End Longitude
STC2	26/04/2023	2	19:00	20:00	Santiago	São Filipe	14.98752	-23.53353	14.98530	-23.52904
STC2	26/04/2023	3	21:00	22:00	Santiago	São Filipe	14.98752	-23.53353	14.98530	-23.52904
STW1	12/10/2023	2	19:30	19:45	Santiago	São Filipe	14.9675	-23.5120	14.9695	-23.5085
STC1	13/10/2023	2	18:46	19:01	Santiago	São Filipe	14.9860	-23.5341	14.9695	-23.5342
STC2	13/10/2023	2	19:07	19:23	Santiago	São Filipe	14.9873	-23.5335	14.9881	-23.5326
STC3	13/10/2023	2	19:50	20:08	Santiago	São Filipe	14.9920	-23.5248	14.9940	-23.5255
ad hoc_1	14/10/2022	7	18:00	18:05	Santiago	Praia	14.9240	-23.5024	14.9240	-23.5024
ad hoc_2	14/10/2023	7	18:40	19:00	Santiago	Praia	14.9541	-23.4788	14.9533	-23.4793
STW	15/10/2023	2	17:00	18:45	Santiago	São Filipe	14.9667	-23.5051	14.9770	-23.5205
STW3	15/10/2023	2	18:46	19:01	Santiago	São Filipe	14.9770	-23.5205	14.9744	-23.5166
STW2	15/10/2023	2	19:17	19:32	Santiago	São Filipe	14.9738	-23.5158	14.9707	-23.5126
STC2	15/10/2023	2	20:06	20:21	Santiago	São Filipe	14.9873	-23.5335	14.9881	-23.5326
STC1	15/10/2023	2	20:24	20:39	Santiago	São Filipe	14.9860	-23.5341	14.9695	-23.5342
ad hoc_3	16/10/2023	3	19:05	19:25	Santiago	São Jorge	15.0510	-23.6087	15.0504	-23.6073
ad hoc_3	16/10/2023	3	19:43	20:03	Santiago	São Jorge	15.0484	-23.6174	15.0484	-23.6174
SW	17/10/2023	2	17:30	19:30	Sal	Murdeira	16.7076	-22.9051	16.6960	-22.8969
SW2	17/10/2023	2	19:35	19:50	Sal	Murdeira	16.7076	-22.9051	16.7031	-22.9034
SW1	17/10/2023	2	20:03	20:18	Sal	Murdeira	16.6960	-22.8969	16.6981	-22.9010
SC2	17/10/2023	2	20:40	20:55	Sal	Espargos	16.7204	-22.9141	16.7217	-22.9178
SC1	17/10/2023	2	21:03	21:18	Sal	Espargos	16.7240	-22.9228	16.7246	-22.9279
SW	18/10/2023	3	17:30	19:30	Sal	Murdeira	16.6960	-22.8969	16.7076	-22.9051
SW2	18/10/2023	2	19:00	19:15	Sal	Murdeira	16.7076	-22.9051	16.7031	-22.9034
SW1	18/10/2023	2	19:20	19:35	Sal	Murdeira	16.6960	-22.8969	16.6981	-22.9010
SC1	18/10/2023	3	20:07	20:18	Sal	Espargos	16.7246	-22.9279	16.7240	-22.9228
SC2	18/10/2023	3	20:33	20:48	Sal	Espargos	16.7217	-22.9178	16.7204	-22.9141
STW3	19/10/2023	2	23:38	23:53	Santiago	São Filipe	14.9770	-23.5205	14.9744	-23.5166
STW2	19/10/2023	2	23:58	00:13	Santiago	São Filipe	14.9738	-23.5158	14.9707	-23.5126
STW1	19/10/2023	2	00:20	00:35	Santiago	São Filipe	14.9675	-23.5120	14.9695	-23.5085
STW	20/10/2023	2	11:10	13:10	Santiago	São Filipe	14.9770	-23.5205	14.9667	-23.5051
STC3	20/10/2023	5	20:07	20:27	Santiago	São Filipe	14.9920	-23.5248	14.9940	-23.5255

Baseline for genetic diversity of reptile and bat taxa

Extraction of the DNA from tail or skin tissues was performed using standard high-salt protocol (Vasconcelos et al. 2012). It was followed by amplification of the mitochondrial DNA of the cytochrome b (cyt b) for *Hemidactylus* and *T. nudiventris* and 12S rRNA marker for *Tarentola* and *Chioninia* using the primers cytb1 and cytb2, cyt b F_Tn and cyt b R_Tn, and 12SA and 12SB, respectively, following the methods described in Miralles et al. (2011), Pinho et al. (2023), and Borloti et al. (2020). Sanger sequencing was performed on a 3100 Applied Biosystems DNA Sequencing Apparatus and sequences aligned using Geneious R6 (www.geneious.com). Blast (https://blast.ncbi.nlm.nih.gov) algorithm was used to compare the output sequences with others available in GenBank and to assess genetic diversity.

Results

Main threats affecting the target reptiles, bats and their habitat

We have detected several main threats to the reptile species, such as the presence of introduced mammals, reptiles and amphibians, namely monkeys, toads and geckos in the windfarm of Santiago or control area, and cats and geckos, in the windfarm or control area on Sal (**Fig. 2**). Cats can be a treat to some bat species as well.

On Santiago, inside the windfarm area green monkeys were reported by the guards, and faecal pellets were collected to confirm their taxonomic identification, and introduced *Hemidactylus angulatus* geckos were more abundant (N=23) than in the control area (N=5). Introduced African common toads *Sclerophrys regularis* (Vasconcelos et al. 2010) were also observed near the entrance gate and tissue samples were collected for genotypic identification. On Sal, at least three cats were observed in April near the housing of the guards that confirmed that they usually predate on reptiles, birds and other animals. Introduced cats were removed from Sal windfarm in October. Inside the windfarm area, we detected no introduced reptiles while outside in the control area they were abundant (N=14).

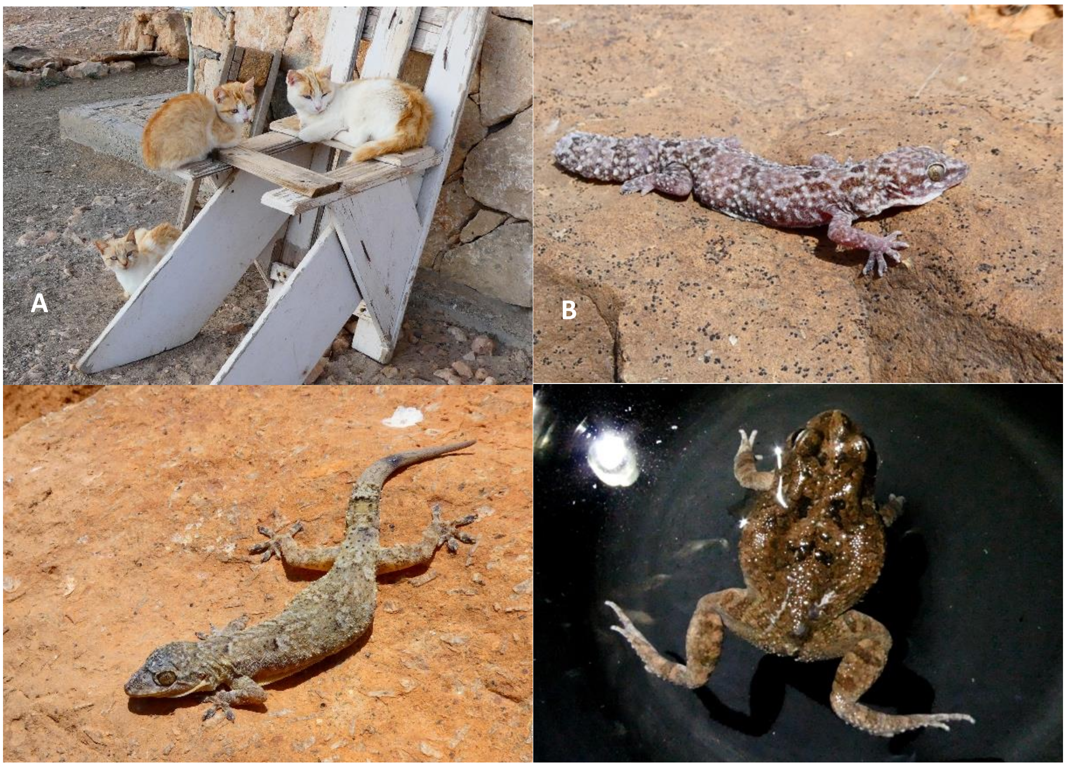


Fig. 2. Introduced fauna detected in the windfarm and control areas. **A)** Feral cats, Sal windfarm area. **B)** and **C)** Invasive *Hemidactylus* geckos, Santiago windfarm area and Sal control area. **D)** Common African toad, Santiago windfarm area.

As threats to the habitat, we have detected some overgrazing by cows and goats, especially in Santiago windfarm. Finally, we found evidences of threats to other native animals that may indirectly affect endemic reptiles and bats, such as human hunting activities, namely inside the windfarm on Santiago (**Fig. 3**).

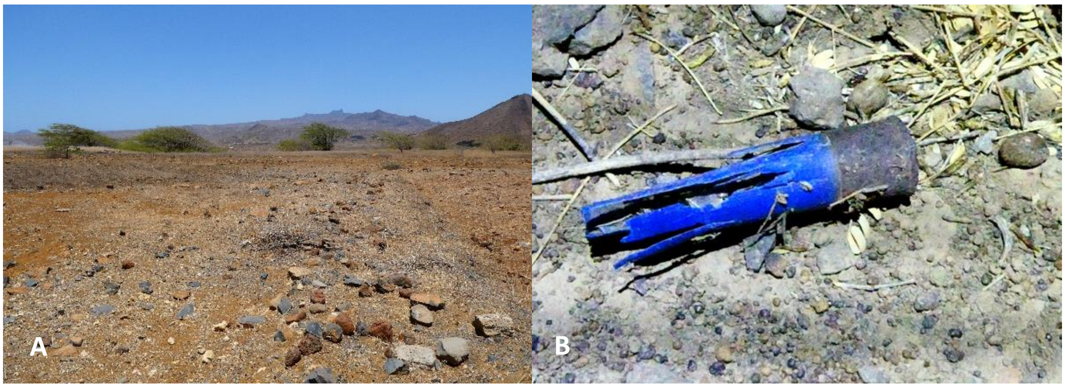


Fig. 3. Habitat threats. **A)** Evidences of overgrazing and **B)** hunting activities.

In addition, we have found three bat carcases with evidence of barotrauma and/ or collision with the wind turbines. We also found at least eight bird carcases of three different species (helmeted guineafowl *Numida meleagris*, osprey Pandion haliaetus and the greater Cabo Verde kestrel *Falco alexandri*) nearby the wind mills suggesting they have collided with the turbines or the wind towers. All this information is detailed in **Table 2**.

Table 2. List of animal remains found nearby the wind mills during the mortality assessment transects. The date, island and coordinates of their finding, the taxonomic identification and code are also given. A short explanation about the appearance of the remains and estimated time of dead is detailed in the Notes.

Date	Island	Latitude	Longitude	Taxa	Code	Notes
15.10.2023	Santiago	14.96671	-23.50509	*Taphozous nudiventris*	ST10.23_Tn1	Recent, likely barotrauma
15.10.2023	Santiago	14.96954	-23.51023	*Numida meleagris*	S10.23_Nm1	>2 days old
17.10.2023	Sal	unk	unk	*Pandion haliaetus*	S10.23_Ph1 (J2†)	foot at Cabeólica's
17.10.2023	Sal	16.70251	-22.90186	*Mus musculus*	S10.23_Mm	In raptors' pellet
17.10.2023	Sal	16.70010	-22.90019	large bird bone fragments	S10.23_bones	*Pandion*?
17.10.2023	Sal	16.69670	-22.89688	*Falco alexandri*	S10.23_Fa1	>3 days
18.10.2023	Sal	16.69896	-22.89934	*Pandion haliaetus*	S10.23_Ph2	Bones, >1 week
18.10.2023	Sal	16.69894	-22.89925	*Falco alexandri*	S10.23_Fa2	Bones, > 1 week
18.10.2023	Sal	16.70026	-22.90013	*Pandion haliaetus*	S10.23_Ph4	Nails, > 1 week
18.10.2023	Sal	16.70026	-22.90013	*Pandion haliaetus*	S10.23_Ph3	Very old (same ind?)
18.10.2023	Sal	16.70148	-22.90093	turtle	S10.23_turtle	Juvenile
20.10.2023	Santiago	14.97157	-23.51360	*Falco alexandri*	ST10.23_Fa3	Complete, 2 weeks
20.10.2023	Santiago	14.97032	-23.51200	*Numida meleagris*	ST10.23_Nm2	Complete, <5 days old
20.10.2023	Santiago	14.96643	-23.50495	*Taphozous nudiventris*	ST10.23_Tn2	Half (tail and feet)
20.10.2024	Santiago	14.97019	-23.51206	*Taphozous nudiventris*	ST10.23_Tn3	Recent trauma

Identification of reptile and bat taxa

Regarding reptiles, on Santiago we confirmed the presence of Santiago wall gecko *Tarentola rudis*, Delalande' skink *Chioninia delalandii*, and Santiago skink *Chioninia spinalis santiagoensis* both inside and outside the windfarm area. The presences of the Darwin's wall gecko *Tarentola darwini* is pending further sampling in future monitoring during the dry season. The presence introduced Brook's house gecko *Hemidactylus angulatus* was confirmed both inside and outside the windfarm area. On Sal we confirmed the presence of Sal skink *Chioninia spinalis salensis* and the absence of Sal leaf-toed gecko *Hemidactylus boavistensis chevalieri* inside and outside the windfarm area. The presence of the introduced *H. angulatus* and *Hemidactylus mabouia* geckos was confirmed by genetic analyses.

Regarding bats, recordings (n=42) and morphological observation of the collected vouchers positively identified 1 species (*Taphozous nudiventris*) of bat in the windfarm and control area on Santiago.

Table 3. List of performed ultrasounds recording. The file name indicates the software automatic identification (when the file starts with numbers, there was no automatic bat detection), followed by date and hour. Bat ID represents the manual identification. The minimum number of bats present in each recording (Min N) and some of the most important pulse characteristics (frequency of maximum energy, FmaxE, duration and shape, CF stands for constant frequency) used for bat identification are also given.

File name	Bat ID	Min N	FmaxE (khz)	Duration (ms)	Shape
NoID_20231013_200719	*Taphozous nudiventris*	1	25	31	CF
20231013_201554	*Taphozous nudiventris*	1	24	41	CF
20231013_201356	*Taphozous nudiventris*	1	25	38	CF
TADTEN_20231014_185604	*Taphozous nudiventris*	2	25	18	CF
TADTEN_20231014_185954	*Taphozous nudiventris*	1	24	16	CF
TADTEN_20231014_190029	*Taphozous nudiventris*	1	27	24	CF
TADTEN_20231014_190057	*Taphozous nudiventris*	1	22	33	CF
TADTEN_20231014_190117	*Taphozous nudiventris*	3	27	17	CF
TADTEN_20231014_190449	*Taphozous nudiventris*	1	25	15	CF
HYPSAV_20231013_201824	*Taphozous nudiventris*	1	25	36	CF
HYPSAV_20231014_185413	*Taphozous nudiventris*	1	24	36	CF
HYPSAV_20231014_185452	*Taphozous nudiventris*	2	24	31	CF
NoID_20231014_190137	*Taphozous nudiventris*	1	23	21	CF
NoID_20231014_190307	*Taphozous nudiventris*	1	25	23	CF
NoID_20231014_190409	*Taphozous nudiventris*	2	23	30	CF
NoID_20231014_190428	*Taphozous nudiventris*	1	23	29	CF
NoID_20231014_190509	*Taphozous nudiventris*	1	25	26	CF
HYPSAV_20231014_185529	*Taphozous nudiventris*	1	25	29	CF
HYPSAV_20231014_185637	*Taphozous nudiventris*	1	23	27	CF
HYPSAV_20231014_185814	*Taphozous nudiventris*	1	24	23	CF
HYPSAV_20231014_190014	*Taphozous nudiventris*	1	26	15	CF
HYPSAV_20231014_190155	*Taphozous nudiventris*	2	28	14	CF

HYPSAV_20231014_190328	*Taphozous nudiventris*	2	24	20	CF
HYPSAV_20231014_190349	*Taphozous nudiventris*	2	24	20	CF
NoID_20231013_201338	*Taphozous nudiventris*	1	24	31	CF
NoID_20231013_201857	*Taphozous nudiventris*	1	23	36	CF
NoID_20231014_185432	*Taphozous nudiventris*	1	25	28	CF
NoID_20231014_185623	*Taphozous nudiventris*	2	27	21	CF
NoID_20231014_185834	*Taphozous nudiventris*	1	26	21	CF
NoID_20231014_185856	*Taphozous nudiventris*	1	24	23	CF
NoID_20231014_185934	*Taphozous nudiventris*	1	24	27	CF
HYPSAV_20231015_192237	*Taphozous nudiventris*	1	23	22	CF
NoID_20231015_193031	*Taphozous nudiventris*	1	25	19	CF
NoID_20231015_200805	*Taphozous nudiventris*	1	24	22	CF
NoID_20231015_200822	*Taphozous nudiventris*	1	23	23	CF
NoID_20231015_201941	*Taphozous nudiventris*	1	24	20	CF
NoID_20231015_202636	*Taphozous nudiventris*	1	24	19	CF
NoID_20231020_000745	*Taphozous nudiventris*	1	24	20	CF
NYCLEI_20231020_000726	*Taphozous nudiventris*	1	24	21	CF
NYCLEI_20231020_000805	*Taphozous nudiventris*	1	24	32	CF
NYCLEI_20231020_003645	*Taphozous nudiventris*	1	25	23	CF
NYCLEI_20231020_201214	*Taphozous nudiventris*	1	26	11	CF

Baseline for genetic diversity of reptile and bat taxa

Regarding *Tarentola rudis*, all individuals, both inside and outside the windfarm, presented the same haplotype as the one found in Ribeirão Chiqueiro. One individual with no clear phenotype presented a *T. darwini* haplotype. That haplotype matched the one presented by hybrid individuals from the south of the island, namely from Praia Baixo.

For *Chioninia delalandii* we found similar diversity inside and outside the windfarm (one haplotype versus two, respectively). Inside the windfarm we found a widespread haplotype, the same as individuals occurring on Santa Maria Islet, Picos, Chão Bom and Santa Catarina. Outside the windfarm we found also two widespread haplotypes, including the most common in this species. For *Chioninia spinalis santiagoensis* we found four haplotypes that are distributed in the regions around Praia, from Santa Ana to Ribeirão Chiqueiro.

For evaluating the genetic diversity of bats we were able to amplify circa 150 base pairs of cyt *b* marker. All samples confirmed the morphological and acoustic identification of *Taphozous nudiventris* with 100% identity with samples from Ghana, Oman and Sudan (GenBank accession codes: MN064350 – MN064356, and MN064362 – MN064385, MN0643). This must be due to the sequences' shorter size, as the DNA was already degraded since it was collected from dead individuals, as we expected them to be similar to those but with unique mutations as reported by Borloti et al. (2020).

Other deliverables: Training and knowledge transfer

The team was open to train Cabo Verdean students and staff from Protected Areas (PAs) and ONGs in herpetological species identification and methods to capture and collect their samples. Thus, in the first trip, a Cabo Verdean student from University of Cabo Verde (UniCV), Jassira Reis accompanied us for training during one day for sampling in the control area in Santiago (**Fig. 2A**). In the second trip, staff from the Cabo Verdean NGOs Biosfera and Projecto Biodiversidade accompanied us for training and expertise exchange on Santiago and Sal, respectively (**Fig. 2B**). In this way, monitoring in the following years could be performed with national experts.

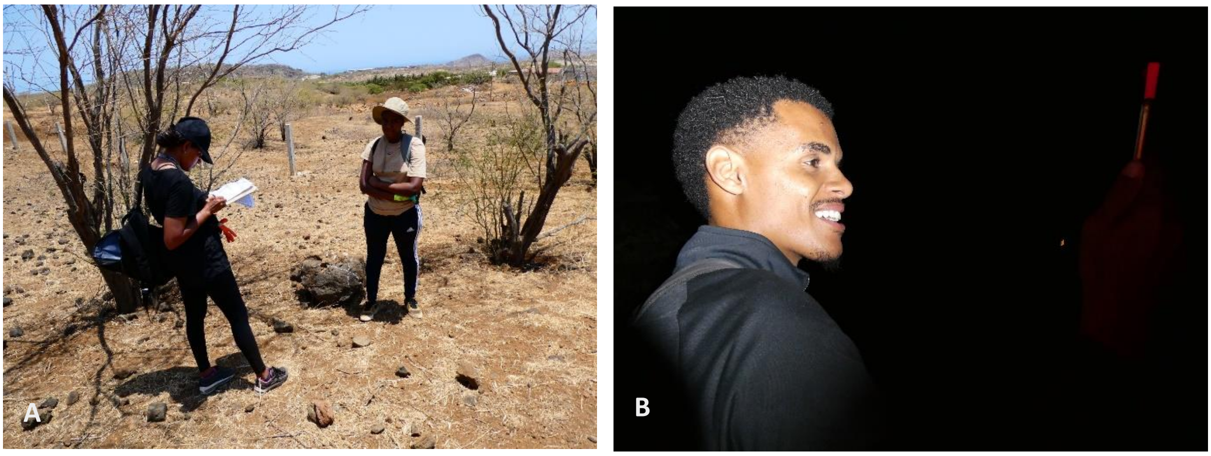


Fig. 2. Training and expertise exchange. **A)** Training of a student from the University of Cabo Verde in herpetological sampling techniques by the Cabo Verdean PhD student Lara Almeida. **B)** Training of a member of a Cabo Verdean NGO on the chiropterogical sampling techniques.

In addition, staff from Cabeólica S.A. was sampling with us for knowledge transfer. During the first trip, Eng. Telma Veiga was sampling reptiles for one night on Santiago, and, during the second trip, Eng. Décio Lopes was assessing the impact of the windmills on bats during the day on Sal (**Fig. 3**).

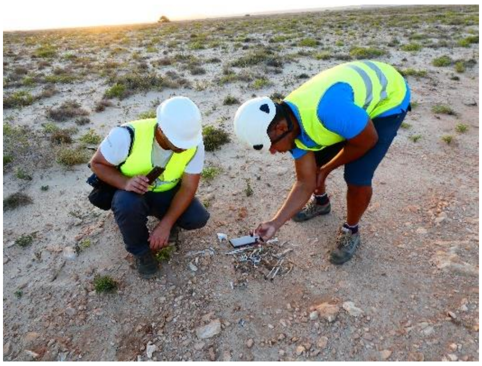
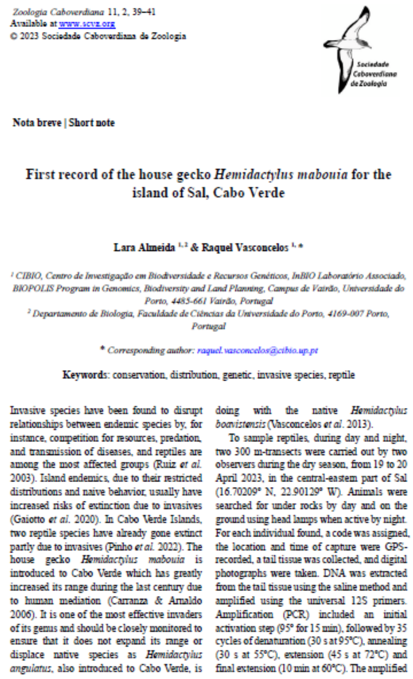


Fig. 3. Knowledge transfer between BIOPOLIS and Cabeólica teams.

Other deliverables: Scientific articles

A short note about the introduction of *H. mabouia* detected for the first time on Sal Island was accepted to be publish in the journal *Zoologia Caboverdiana* (**Fig. 4**).



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Nota breve | Short note

First record of the house gecko *Hemidactylus mabouia* for the island of Sal, Cabo Verde

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Keywords: conservation, distribution, genetic, invasive species, reptile

Invasive species have been found to disrupt relationships between endemic species by, for instance, competition for resources, predation, and transmission of diseases, and reptiles are among the most affected groups (Ruiz *et al.* 2003). Island endemics, due to their restricted distributions and naive behavior, usually have increased risks of extinction due to invasives (Gaiotto *et al.* 2020). In Cabo Verde Islands, two reptile species have already gone extinct partly due to invasives (Pinho *et al.* 2022). The house gecko *Hemidactylus mabouia* is introduced to Cabo Verde which has greatly increased its range during the last century due to human mediation (Carranza & Arnaldo 2006). It is one of the most effective invaders of its genus and should be closely monitored to ensure that it does not expand its range or displace native species as *Hemidactylus angulatus*, also introduced to Cabo Verde, is doing with the native *Hemidactylus boavistensis* (Vasconcelos *et al.* 2013).

To sample reptiles, during day and night, two 300 m-transects were carried out by two observers during the dry season, from 19 to 20 April 2023, in the central-eastern part of Sal (16.70209° N, 22.90129° W). Animals were searched for under rocks by day and on the ground using head lamps when active by night. For each individual found, a code was assigned, the location and time of capture were GPS-recorded, a tail tissue was collected, and digital photographs were taken. DNA was extracted from the tail tissue using the saline method and amplified using the universal 12S primers. Amplification (PCR) included an initial activation step (95° for 15 min), followed by 35 cycles of denaturation (30 s at 95°C), annealing (30 s at 55°C), extension (45 s at 72°C) and final extension (10 min at 60°C). The amplified

Fig. 4. Publication layout. This short note to be published in *Zoologia Caboverdiana* about the introduced geckos found in the control area near the windfarm on Sal.

Other deliverables: Science communication

During the first trip, the team attended the international Flora and Natural Resources of the Cabo Verde Islands Symposium (**Fig. 5A**), hosted by UniCV in Praia. Raquel Vasconcelos presented scientific communications and Cabeólica, S.A. was acknowledged.

During the second trip, the team was searching for bats in the control areas on Santiago with local citizens, communicating about the importance of bats in the ecosystem (**Fig. 5B**).

After the first trip, the work on the introduced reptiles detected on Sal was accepted as a poster communication at the international conferences on the 12th Trends in Biodiversity and Evolution 2023 (TiBE): Invaders on the Horizon! Advancing Invasion Science from Genes to Ecosystems and Society held in Vila do Conde, Portugal, and XIX Annual Meeting of Portuguese Association for Evolutionary Biology (XIX ENBE 2023) held in Lisbon, Portugal, and presented by Lara Almeida (**Fig. 6**).

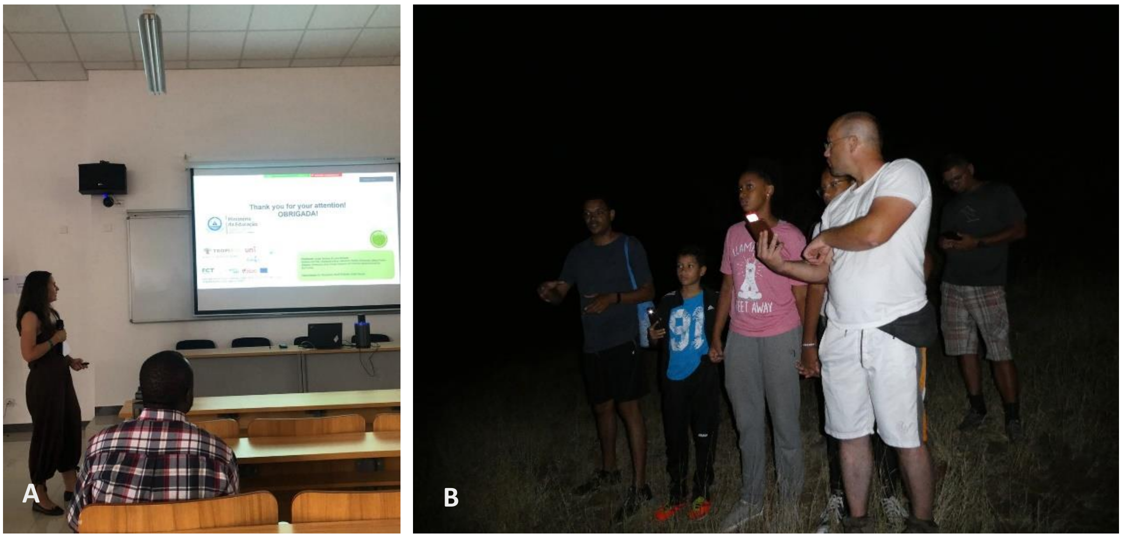

Fig. 5. Science communication. **A)** Oral communication at an international congress at the University of Cabo Verde, Praia, Santiago. **B)** Sampling with local citizens on Praia, Santiago.

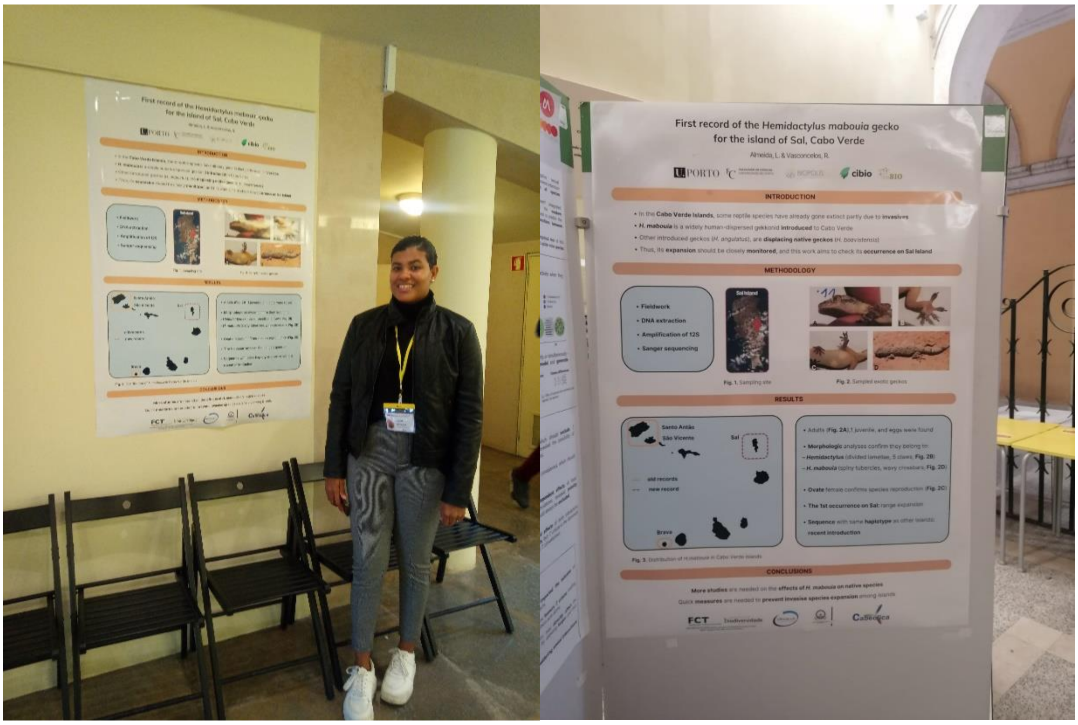

Fig. 6. Science communication. **A)** Poster communication at an international congress at the Municipal Auditorium of Vila do Conde, Portugal and **B)** at Instituto Superior de Agronomia, Universidade Lisboa, Portugal.

Discussion

It was clear from the first survey that one of the main threats affecting the target reptiles, bats and their habitat inside the windfarms are introduced vertebrates. Invasive species have been found to disrupt relations between endemic species and their ecosystem, for instance, by competition for resources, predation, and transmission of diseases, and reptiles are among the most affected groups since they are there is a lack of studies and models to predict such invasions (Pinho et al. 2023). Bat are also affected, especially on islands (Griffiths et al. 2017).

On islands, native reptile and bat species have often evolved and adapted to peculiar lifestyles, for example, to have smaller clutches with larger-sized offspring in the case of the first (Novosolov et al. 2013) and diurnal activity patterns in the case of the latter (Moore 1975). Additionally, insular reptile populations tend to lose their escape behaviour due to the rarity or lack of predators and, thus, are more susceptible to introduced mammal predators (Pinho et al. 2022), such as cats. Finally, the usual small ranges of endemic reptiles make them particularly sensitive to anthropogenic changes and extinction, especially if already classified as Near Threatened, as it is the case of the Sal skink (Vasconcelos 2013b).

Thus, the presence of cats and *H. angulatus* geckos inside the windfarms in Sal and Santiago, respectively, should be controlled and monitored. Considering that the cat may one of the responsible for the extinction of an endemic skinks in Cabo Verde (Miralles et al. 2011), and responsible for impacts on 86 bats species around the world (Oedin et al. 2021), banning its entrance and feeding or new introductions in the windfarms is recommended for protecting the herpeto and chiropterofauna. Also, *H. angulatus* is probably displacing some populations of the endemic geckos on Boavista information regarding the extent of this threat within the windfarm is important and monitoring is required (Vasconcelos et al. 2013). It is also important to refrain the possible entrance of *H. mabouia* geckos inside the windfarm area on Sal, as this species was detected in the surrounding areas and can easily establish populations in urban and semi-urban habitats by taking advantage of insect clusters that form around artificial light sources (Pinho et al. 2023). This species may inhibit native species from the possibility of approaching these high food-density places (Pinho et al. 2023). It is amongst the most successful invasive reptile species in the world, as depicted by its worldwide distribution and rapid spread within the Cabo Verde Archipelago (Pinho et al. 2023). It was for the first time detected in the country in 2001 on São Vicente and later on Santo Antão and Brava (Vasconcelos et al. 2013), and for the first time confirmed on Sal Island in this study. Regarding the common African toad, probably introduced from Guinea-Bissau, the impact that it might have on native invertebrates or indirectly on the vertebrate community dynamics is unknown and further studies are warranted to this (Vasconcelos et al. 2010).

Genetic analyses of the introduced geckos confirmed the taxonomic identification at species level, as these species can present quite similar morphologies and belong to species complexes (Pinho et al. 2023). The haplotypes found for *H. mabouia* from Sal matched the ones previously found on São Vicente and Santo Antão, confirming its recent expansion (Pinho et al. 2023). Only one haplotype for *H. angulatus* was found for individuals from Sal and Santiago and identical to the ones previously published as expected (Vasconcelos et al. 2013). However, for the endemic geckos, as hybridization between *T. darwini* and *T. rudis* may occur, even though we found mitochondrial DNA of that first species, we cannot confirm *T. darwini* presence. The fact that the haplotype found is the same as some hybrid individuals following Miralles et al. (2011) reinforces the possibility that the individual found may be a hybrid instead of a *T. darwini*. Thus, further sampling is needed in the following years to confirm the presence of the species.

Some other habitat restoration for the reptile community would include adding more refugees for the animals, such as piles of big rocks. For management actions, we recommend betting on education for sustainable development, by transforming the abandoned building next to the guard house in Santiago windfarm (**Fig. 7A**) into a biodiversity exhibition hall, where some information and photos of the local fauna, including reptiles and bats, could be presented all year round to visitors and local students. Some outdoor posters or paintings about biodiversity could be also placed outside of the buildings in Sal windfarm (**Fig. 7B**).

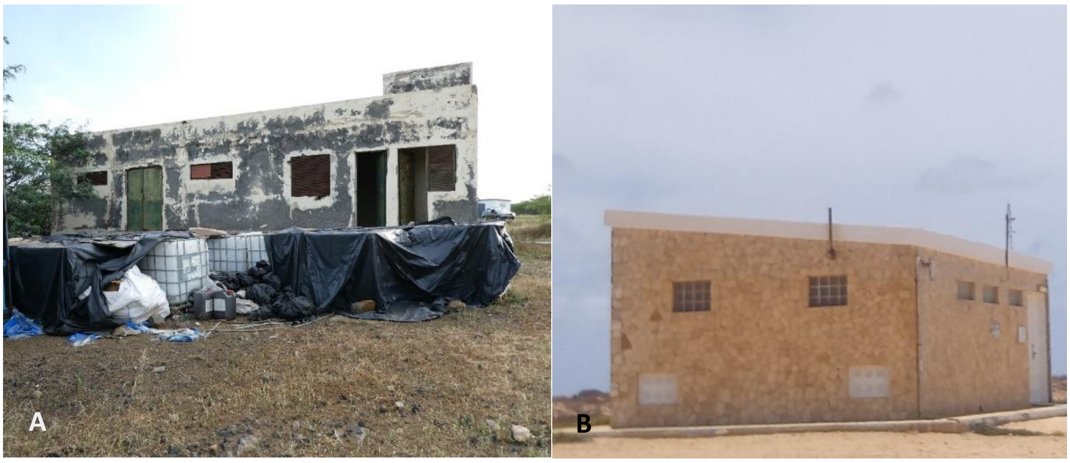

Fig. 7. Potential sites for education for sustainable development. **A)** In Santiago windfarm and **B)** in Sal windfarm.

The mortality of bats on windfarms is highly dependent on their location and weather conditions, due to differences in bat activity (Arnett et al. 2008, Rydell et al. 2010, Salguero et al. 2023). Windfarms also have different impacts depending on the bat species, and open-air foraging species are particularly affected (Arnett et al. 2008, Peste et al. 2015, Rydell et al. 2010, Salguero et al. 2023). Bat mortality is not only due to the collision with the windmill but is also related to barotrauma caused by rapid air pressure changes near the rotating blades, which can result in internal injuries to the bats (Baerwald et al. 2008). Unfortunately, it has been confirmed that the Santiago windfarm is affecting at least one bat species, the naked-rumped tomb bat *Taphozous nudiventris*, an open-air foraging species. This species is listed as Least Concern on a global scale by the IUCN (Monadjem et al. 2017). Nonetheless, there is no available information on the species populations in Cabo Verde, making it very challenging to evaluate the potential impact of wind farms on its populations.

The impact of windfarms on bats, as with other wildlife, should first and foremost attempt to be avoided. If not avoidable, efforts should be made to reduce, moderate and minimise the impact. Ultimately, measures should be taken to offset and compensate the impacts (Peste et al. 2015). One initial step to try to reduce, moderate, and minimize the impact will be to increase the current gap in the knowledge of chiropterofauna in the country, particularly on Santiago Island. On one hand, identifying when the local bat population is active is an essential step. On the other hand, evaluating bat mortality in wind farms and identifying the most problematic sites (windmills) is another one. One of the most cost-effective measures to reduce bat mortality in wind farms is to increase the wind turbine cut-in speed (the velocity at which turbines start producing electricity), usually from values of 5.0 to 6.5m, which typically result in marginal annual power losses (Arnett et al. 2008, Arnett et al. 2011, Peste et al. 2015, Rnjak et al. 2023). Acoustic bat deterrents are another promising option to minimize bat mortality, with some already commercially available. However, they are generally considered a more expensive measure that still requires further development (Peste et al. 2015, Romano et al. 2019, Weaver et al. 2020). This option also seems to yield better results when used in conjunction with wind curtailment (Good et al. 2022). Having a more comprehensive understanding of when bats are locally more active, specifically considering the time of year (seasons), nightly patterns (hours), and associated weather conditions such as wind velocities, would significantly facilitate the implementation of highly cost-effective measures to mitigate the adverse effects of wind farms on bats. If it is also feasible to pinpoint particularly impactful sites (windmills), where mortality is higher, through regular mortality surveys, implementing mitigation measures such as wind curtailment could be achieved with minimal power production losses. Finally, there is the possibility of mitigating the impact on the bat population in the windfarm area by improving conditions for bat populations in other locations. One widely used strategy involves safeguarding bat roosts from disturbance. However, implementing this measure in Santiago would require a deeper understanding of the local bat population, given the current lack of identified bat roosts. Additional common measures include preserving natural habitats, where bat activity tends to be higher, and establishing water points, essential for the drinking needs of most bat species (Peste et al. 2015). It is crucial to emphasize the limited knowledge of bat ecology across all Cabo Verde islands. Enhancing mitigation or compensation measures would greatly benefit from a more comprehensive understanding of the local bat ecology.

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