Remote sensing as a tool to analyse lizard's behaviour

Remi Dos Santos*[a], Ana C. Teodoro[b,c], Miguel Carretero[d], Neftalí Sillero[a]
[a]Centro de Investigação em Ciências Geo-Espaciais (CICGE) (Portugal); [b]Instituto de Ciências da Terra (ICT) (Portugal); [c]Departamento de Geociências, Ambiente e Ordenamento do Território da Faculdade de Ciências da Universidade do Porto (Portugal); [d]CIBIO Research Centre in Biodiversity and Genetic Resources, InBIO, Univerisidade do Porto (Portugal);

ABSTRACT

Although the spatial context is expected to be a major influence in the interactions among organisms and their environment, it is commonly ignored in ecological studies. This study is part of an investigation on home ranges and their influence in the escape behaviour of Iberian lizards. Fieldwork was conducted inside a 400 m^2 mesocosm, using three acclimatized adult male individuals. In order to perform analyses at this local scale, tools with high spatial accuracy are needed. A total of 3016 GPS points were recorded and processed into a Digital Elevation Model (DEM), with a pixel resolution of 2 cm. Then, 1156 aerial photos were taken and processed to create an orthophoto. A refuge map, containing possible locations for retreats was generated with supervised image classification algorithms, obtaining four classes (refuges, vegetation, bare soil and organic soil). Furthermore, 50 data-loggers were randomly placed, recording evenly through the area temperature and humidity every 15’. After a month of recording, all environmental variables were interpolated using Kriging. The study area presented an irregular elevation. The humidity varied according to the topography and the temperature presented a West-East pattern. Both variables are of paramount importance for lizard activity and performance. In a predation risk scenario, a lizard located in a temperature close to its thermal optimum will be able to escape more efficiently. Integration of such ecologically relevant elements in a spatial context exemplifies how remote sensing tools can contribute to improve inference in behavioural ecology.

Keywords: Lizard, Spatial analysis, RTK-GPS, Digital Elevation Model, Orthophoto, Image Classification, Kriging

1. INTRODUCTION

Although the spatial context is expected to be a major influence in the interactions among organisms and their environment, it is commonly ignored in ecological studies. Therefore, remote sensing data and Geographical Information Systems (GIS) tools could be an excellent alternative to traditional methods granting higher accuracy of environmental estimation. When trying to avoid predation, some prey species developed different antipredator mechanisms, which are responses to survive a predatory attack. These can be divided into three main classes: behavioural, morphological or physiological[1]. The most common antipredator behaviours are escaping and immobility (e.g. crypsis, thanatosis), both aiming at discouraging the predator. Behavioural decisions represent a risk and cost to the individual, requiring an evaluation of the environment and, hence, of its spatial structure. Crypsis is the most common morphological adaptation, and is widely present through species and intends to avoid to be detected by the predator[2]; Physiological adaptations include chemical compounds, either toxic or unpleasant somehow, with the purpose of deviating the predator attention. Many species have multiple antipredator mechanisms. In the case of reptiles, small lizards usually have a colouration and pattern matching the environment but also rely on the escaping when detected[3]. In many species, individuals may shift the predominant behaviour through the life cycle, relying mostly in crypsis as juveniles and escaping as adults. It is also frequent for lizards to shed the tail (autotomy) as a distracting strategy, gaining time to perform the escape and to hide in a refuge while the predator concentrates in the still moving tail. This behaviour carries costs to the lizard, especially in terms of energy, but also regarding locomotion and social status. However, this temporal loss may help the lizard to survive and soon regenerate[4].

Lizards are ectotherm organisms, and thus thermal and hydric environments influence the escape ability (e.g. speed, acceleration) and how much resources are losing when escaping. Gender, age class, body condition, parasitization, and pregnancy influence also the success and/or decision of escape behaviour[5]. Individuals with a poor body condition will take less risk, staying close to refuges, running earlier, or both. In the case of cold thermal conditions, escape should start early and hide in closer refuges, as the running ability is poorer[6]. Pregnant lizards shift the predominant antipredator behaviour, relying in crypsis and staying close to the refuges[7]. These risk-benefit trade-offs are

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well known in behavioural ecology, but the environmental background, such as the spatial context, tends to be poorly evaluated,[8–10]. To our knowledge, no studies have been addressed to find a relationship between the antipredator behaviour and the home range of the individual.

Lizards tend to create site fidelity holding a favourite area where they reaming for most time, the home range. Home range, sometimes mistaken by territory, was defined by Burt, 1943 as: "...the area over which the animal normally travels in food gathering, mating, and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered as in part of the home range". As opposed, the territory is the part of the home range which is protected from conspecifics. The home range is not static, may vary in size and location within the same individual, and across individuals might depend on the sex, age and/or season[11]. The home range is not used uniformly: most individuals will present a preferred area ("core area") within the home range where the individual is more active (e.g. feeding, basking). These generally include the locations of the main refuges and hunting locations[12].

In spatial ecology studies, different data are required: species records, environment information and the relationship between both. Species records are obtained essentially by three different methods: (1) radio-telemetry, which collects the position by the triangulation of several radio signal emitted by a transmitter attached to the animal[14]; (2) local plots, an entirely manual method, where the study area is divided into quadrants, and the individuals are located by measuring the distances to the nearest quadrant borders; and (3) Global Positioning System (GPS) tracking, which provides highly precise data. Attached GPS are limited to large animals due to the battery size and duration[15]. Hand held GPS can be used for local studies, namely when the species are too small to carry a radio-transmitter. The researcher carries the GPS device, searches actively for the individuals, and records the position in situ. Depending on the device, records may be highly precise (e.g. Real-Time Kinematic - RTK-GPS). In terms of environmental features, different information may have a strong relationship with the species' behaviour. Initially, remote sensing methods only provided images with low spatial resolution[16], yet, modern sensors with higher spatial and spectral resolutions allow direct remote sensing of certain biodiversity aspects. These advances permit, for example, the identification of individual species of trees[17] using sensors onboard of air-planes or satellites. For even smaller areas (few square meters) satellites or airplanes do not provide enough spatial resolution to generate accurate aerial photographs. Hence, the alternative methods are using cameras attached to drones or to sticks to generate higher resolution photographs. These methods may provide a centimetre-level resolution[18]. Some more local information, like temperature, humidity or pressure, may also be gathered when associated to the species. For this, data-loggers record the local information in a log for a previously determined time. This method is especially useful for small areas since a big number of devices can be placed allowing a precise interpolation. Alternatively, for temperature recording, a thermal camera allows a continuous thermic monitoring, avoiding interpolation errors. Remote sensing techniques are starting to be part of a major part of spatial ecology studies, namely as data source. For example, remote sensing data sources have been applied in: prediction of species invasions[19], ecological niche modelling[20,21] or epidemology[22]. Relatively to individual-level and in particular to home range, some studies are known to use remote sensing as data source[23,24], though not linked to the animal behaviour.

In this study we aim at evaluating the usefulness of remote sensing techniques in behavioural ecology by integrating them in a pilot study addressed to understand the influence of the home range in the escape behaviour of lizards from a spatial point of view.

2. MATERIALS AND METHODS

2.1. Study location and mesocosm

A mesocosms was built in order to have a controlled environment regarding space and its abiotic structures, hence, minimising the possible external impacts on the species behaviour and consequently its spatial dynamics. The mesocosm ensures a semi-controlled and replicable experimental area, being mostly used for individual level studies. It was built in the Astronomical Observatory Professor Manuel de Barros (41°06'22.6"N, 8°35'18.9"W), in Vila Nova de Gaia, Portugal, and consisted in a 20×20 meter fenced area including a variety of natural low vegetation, tree trunks and rocks. The mesocosm restricts the presence of terrestrial predators which could interfere with the experiments.

2.2. Species used

A lizard species was used in this study: *Podarcis bocagei*, a representative of Family Lacertidae which is the most common lizards in north western Portugal. This small diurnal and insectivorous lizard is endemic to the north-west of the Iberian Peninsula and presents activity throughout the year provided that weather conditions are favourable[25].

2.3. Capture and anatomic measures:

A total of eight adult individuals were captured (five males, and three females) at Madalena beach, Vila Nova de Gaia (Portugal), by noose[26]. After a basic biometric characterization, pictures of the belly of each individual were taken for individual photo-identification. Lastly, each individual was marked with a combination of three non-toxic colour dye. Each combination allowed individual recognitions. Since dye disappears with the skin moulting, a photo-identification was needed to recognise and repaint each individual. For this, the Interactive Individual Identification System (I3S) was used. This software was originally developed to recognise patterns as an individual fingerprint. Later the algorithm was tested with other natural patterns like intersection among chest scales which would be used as fingerprint for lizards[27].

2.4. Orthophoto and digital elevation model:

In order to map the study area with high spatial resolution, a mosaic orthophoto was produced from 1152 photos shot with a Canon PowerShot A495 compact camera and a tripod. The photos were taken using sequential mode and covered the entire area by walking throughout the mesocosm. The mosaic was generated using a photogrammetry software, Agisoft's "Photoscan" version 1.2.0. This software aligns and extracts matching points from the numerous photos, then creates a point cloud. From the point cloud it generates a sparse cloud which includes the texture from the images, and finally it creates the orthophoto generating the textures from the photos and the relief from the matching points. This orthorectified aerial photo nullifies the tilt of the camera and produces a highly accurate representation of the area allowing true distances. Additionally, a digital elevation model (DEM) with a pixel resolution of 2 cm was created using 3016 accurate altitude points obtained with a RTK-GPS (Trimble TSC3 and Trimble R4 receiver) and a triangulated irregular network (TIN) with ArcGIS version 10.3.1 (ESRI, Redlands, USA).

2.5. Temperature, humidity and refuge maps

In order to monitor the environmental conditions of the mesocosm a total of 50 data-loggers (27 Maxim's iButton DS1921G for temperature only and 23 Maxim's iButton DS1923 for humidity and temperature) were randomly placed in the mesocosm using a random algorithm from ArcGIS software. Data-loggers were programmed to record every 15' minutes. All types of abiotic structures were covered (vegetation, bare soil and rocks). Data-loggers were georeferenced using a high precision RTK-GPS (Trimble TSC3 and Trimble R4 receiver). The logs were organised by hours and interpolated with ordinary Kriging in ArcGIS to create hourly maps which describe the spatio-temporal variation of the conditions within the mesocosm.

The orthophoto was classified considering a supervised maximum likelihood classification in ArcGIS with four different classes (refuges, vegetation, bare soil and organic soil) to map potential refuges for lizards in the mesocosm. A refuge was defined as a crack in a rock, a small hole, or an entire rock or bush where the lizard could retreat in. The supervised classes were calculated with four polygons for each class with about: (1) 620 000 pixels for refuges; (2) 210 000 pixels for vegetation; (3) 270 000 pixels for soil; and (4) 240 000 pixels for organic soil.

2.6. Escape behaviour experiment and home range assessment

Fieldwork was conducted in the period between August and November 2015: the escape behaviour experiment being once a week and the home range assessment the next 5 days.

The escape behaviour experiment consisted in a simulated predation scenario, where the predator (the researcher using always similar clothes) walked randomly with a slow pace throughout the mesocosm until a lizard was detected. Then, the researcher started waking directly towards the individual until it escapes. Three spatial positions were recorded with a Trimble GeoExplorer 2008 XM GPS unit: at the start of escape, (1) the position of the predator (Ap) and (2) the position of the lizard (St); and (3) the final location of the lizard (Fn), when it stops in an open space or hide inside a refuge. The time until the individual recovers its activity was recorded with a chronometer. A total of five approaches were done to each individual, during a month. Distances were calculated between Ap-St and St-Fn using distance matrix method, resulting in two distances: approach distance and escape distance.

Concerning the home range assessment, the researcher visited the whole meso-cosmos walking slowly with a random trajectory. A handheld Trimble GeoExplorer 2008 XM GPS was used to record the spatial position of every detected lizard as well as the following data: activity (basking, feeding, mating or running), Position (sun, shade, mixed), habitat and substrate temperature using a laser thermometer. The mesocosm was leaved undisturbed for about 30 minutes after each visit.

Home ranges were calculated using a 95% Minimum Convex Polygon (MCP), one of the simplest techniques developed to estimate home ranges. This technique generates the smallest polygon containing all the detections of the input and requires a minimum of three points (the minimum number to form a polygon) [12]. However, the accuracy of the model for the complete MCP will increase with the number and tend to overestimate the home range area which decreases the reliability. The 95% variation tries to nullify this overestimation by ignoring the 5% of the farthest detections (assuming them as outliers), which ensures a more realistic model of the home range[28]. Individual MCP and escape distances were then overlapped to analyse the direction and final position of each individual regarding the home range. The home ranges and the escapes were added to the DEM in order to be able to measure distances.

3. RESULTS

3.1. Orthophoto and digital elevation model

The study area presented an irregular elevation (Figure 1), varying between 227m and 230m. Aside from the typical irregularities of rocks and tree trunks, the land presents a slope along an east-west axis.

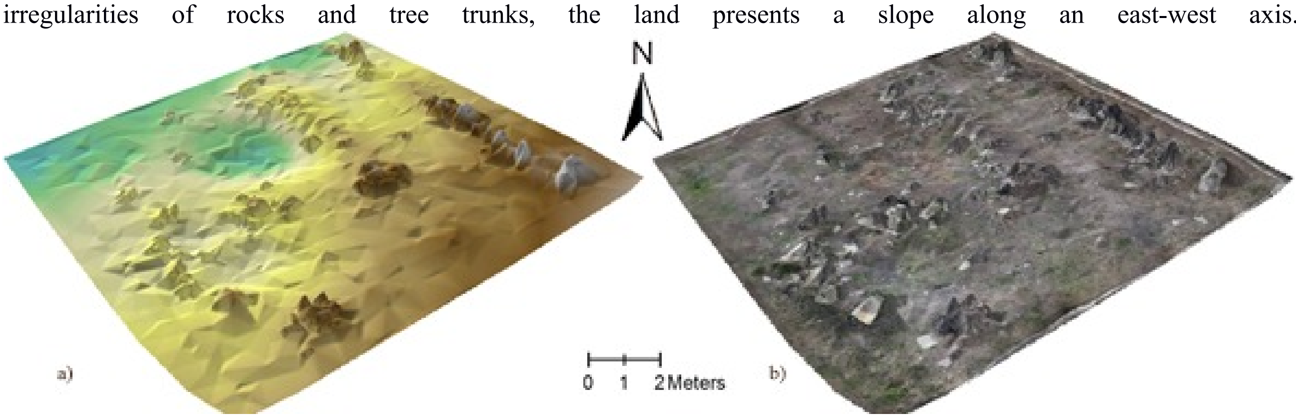

Figure 1 – (a) DEM and (b) Orthophoto of the mesocosm. White colours of the DEM represent higher elevations (230 meters max.), while the blueish colour lower elevations (227 meters min.). Pixel resolution is 2 cm in both maps.

3.2. Temperature map

The study area harboured a widespread range of temperatures throughout the day. The Figure 2 represents the average of all the temperatures, which ranges from 18 °C to16 °C. Looking closer (Table 1), there is a span of temperatures varying between 13.75 °C (the lowest temperature at 7h) and 24.01 °C (higher temperature at 14h). Regarding the humidity, the study area presented low variation of mean values, ranging between 88%H and 82%H. There is, however, a higher variability by hours, grading from 92.52% at 1h to 66.87%H at 14h.

Table 1 - Average of temperatures (°C) for each hour during the study period.

Time	TEMPERATURE (°C)	σ	Relative humidity (%H)	σ
00:00	14.51	1.07	92.29	4.31
01:00	14.42	1.01	92.52	4.26
02:00	14.41	1.12	91.46	4.37
03:00	14.26	1.15	91.41	4.36
04:00	14.14	1.14	91.99	4.29
05:00	14.05	1.17	92.59	4.41
06:00	13.84	0.98	92.86	4.25
07:00	13.75	0.72	93.38	3.93
08:00	14.56	0.62	92.41	4.23
09:00	16.52	1.03	88.72	5.26
10:00	18.86	1.57	82.33	5.98
11:00	21.05	1.92	76.13	6.53
12:00	23.03	2.28	70.30	6.89
13:00	23.96	2.42	67.22	6.57
14:00	24.01	2.59	66.87	6.17
15:00	22.67	2.41	68.44	5.76
16:00	20.53	1.90	73.07	5.56
17:00	18.30	1.46	79.60	5.49
18:00	16.79	1.31	83.73	5.68
19:00	15.88	1.28	86.59	5.70
20:00	15.40	1.21	88.50	5.46
21:00	15.10	1.17	89.82	5.13
22:00	14.86	1.14	90.50	4.70
23:00	14.68	1.12	91.42	4.38

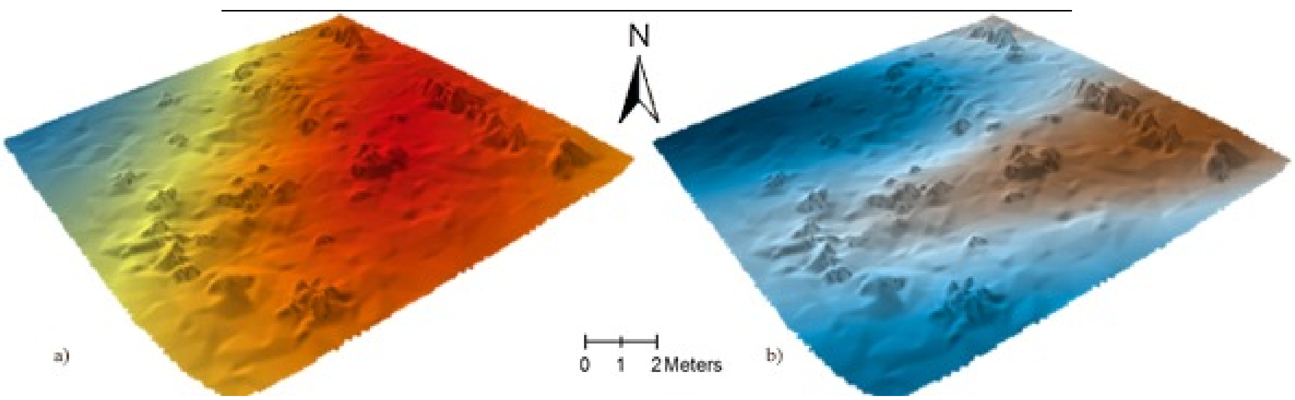

Figure 2 - Average of all (a) temperatures and (b) relative humidity from the period of study.

3.3. Refuge map

From the classification it was obtained a four categories image with a pixel of 2 cm Figure 3 (Table 2).

Table 2 - Refuge map categories, number of pixels and corresponded percentage of area

Category	Number of Pixels	Percentage
Refuges	80465266	6.89
Bare Soil	636999492	54.51
Organic Soil	322918757	27.63
Vegetation	128208910	10.97

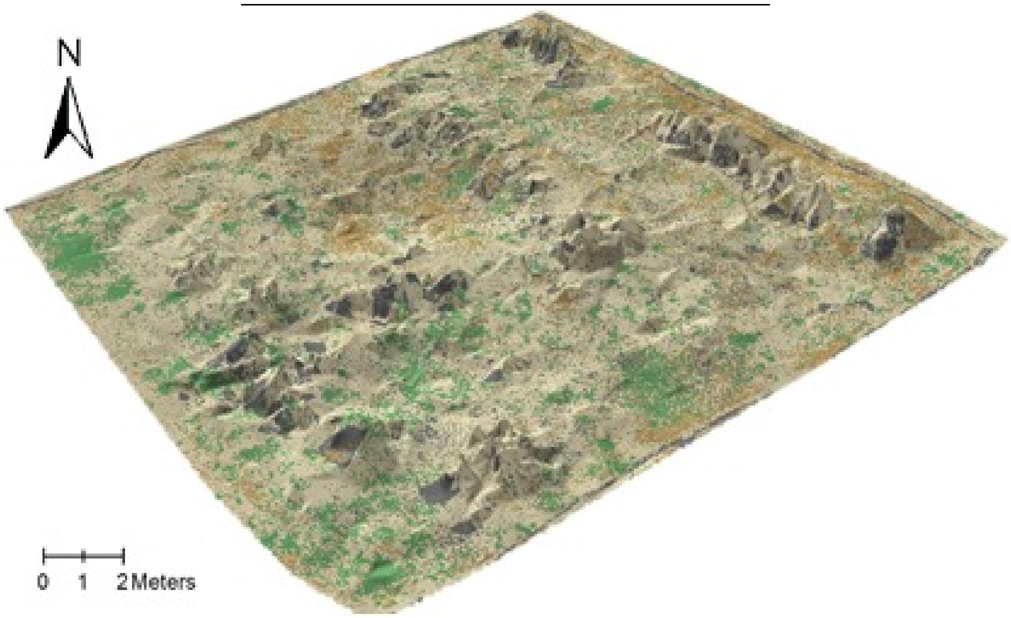

Figure 3 - Refuge map from the image classification. The grey colour represents the potential refuges, the green the vegetation, the dark brown the organic soil and the lighter brown the bare ground.

3.4. Escape behaviour experiments and home range assessment

A total of eight individuals were analysed, but due to the low number of marked locations 95% MCP could be calculated only for three individuals (Table 3).

Table 3 - Area of the 95% MCP of the individuals

Individual	Home range size (m^2)
1	16.27
2	25.19
3	2.11

Five escape routes were analysed for the individual 1, three of them already outside the home range (Figure 4). One of these three escapes resulted in a run into the home range. Of the two escapes inside the home range, both resulted in hiding inside the home range. In the case of the individual 2, of the five escapes, two were outside the home range, and did not re-enter the home range during the escape. From the three escapes inside the home range, two resulted in the exit of the home range. Finally, to the individual 3, four of the five escapes were inside the home range, which two of them ended outside the home range.

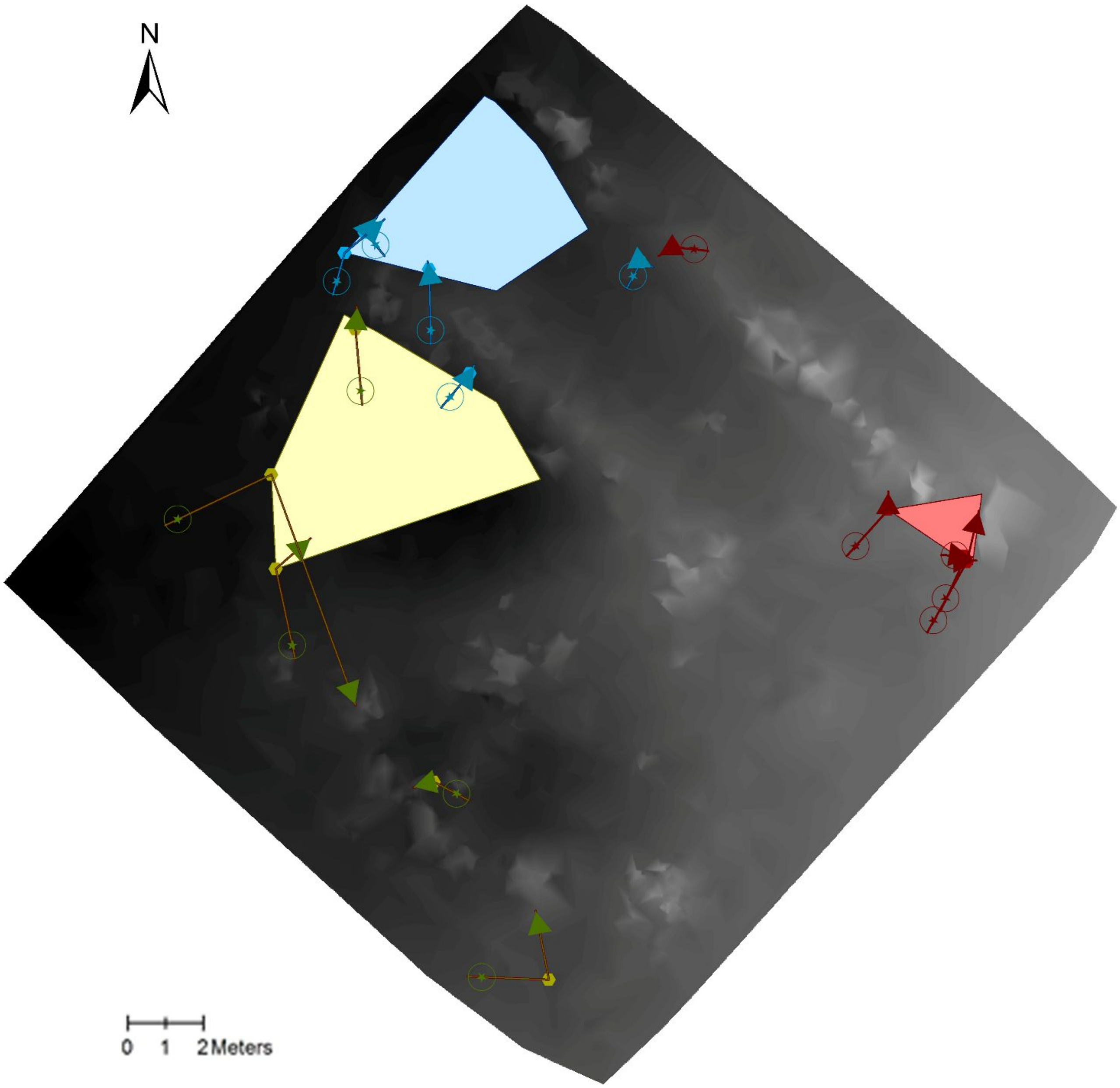

Figure 4 - Home ranges and escape trajectories of three individuals. The circle represents the Ap position, the pentagon the St position and the arrow the Fn position. The blue, yellow, and red colours represent the individuals 1, 2, and 3, respectively.

4. DISCUSSION

Remote sense data source already proved its usefulness in biology studies by providing highly accurate data. Its data are essentially used as direct mapping of a species (e.g. vegetation), habitat mapping and predictions of the species distribution or to establish relationship between environment information and species distribution[29]. Here, these techniques proved useful for the home range estimation and determination of distances traveled by the individuals. However, home range estimators are only as good as the data that are used for the estimation. Both low and high number of locations may either underestimate or overestimate the home range size providing an unreliable representation of the reality[30]. In this case, only three of the individuals previously captured were used due to low number of location, and even there the number of location for the three individuals may not be the more appropriate for a more general estimation. However, for MCPs, the minimum number of locations is only three, which probably will provide a poor estimation. The home range of individual 3 attained only 2.11 square meters and corresponds to a higher location in the DEM, a large rock which allow this lizard to easily hide, thermoregulate and capture preys. For the two other individuals (1 and 2), the home ranges were placed on rocky areas, bare soil and vegetation. Rocks are an essential resource for lizards [31], although these areas may be poor in terms of food inducing more frequent exploring routes. The home range sizes may be explained by the low density of individuals: home ranges will decrease with the increase of individuals' density [30].

Regarding the escape routes of the individuals, there were different approaches to the predation scenario. In the individual 3, a clear preference for escaping towards the home range, which corresponds to a large rock, was observed. The other two individuals (which present similar behaviours) had longer escapes and run always to a rock or vegetation zone, probably due to the topography of the terrain which is mainly bare ground without hiding spots. Similar to the escape, the lizards tended to run away earlier, proving the awareness of the distances, temperatures and time needed to successfully hide[6]. The direction of the approach may also determine how and where the lizards are going to flee, possibly avoiding the return to the home range. Although some of the escape routes finish outside the home range, they keep close in order to ensure a mid-term persistence of the home range.

Regarding other environmental features, lizards tended to occupy warmer and drier areas. The ecological characteristics of the lizards, being ectotherms, accounts for this trend. The environmental conditions prevailing within the mesocosm ensured a good performance for the hunting, reproductive and escape activities, which represent the most time consuming along with thermoregulate[32]. The individuals also tended to run away to a warmer environment, either to a hiding spot like crevices or just further from the predator. Staying in a colder environment will quickly cool the body temperature of the animal and affect its performance, forcing it to thermoregulate again.

Overall, the remote sensing techniques proved to be an essential part of the methodology for this pilot study, once they provide a better understanding of the surrounding environment and the relationship with different organism's activities. The orthophoto, with the assistance of high precision GPS, allowed estimating true distances with high accuracy, crucial for individual-level studies. Drones may be an alternative method to orthophotos, allowing a more stable and constant height during the photo taking. Although this advantage would had indeed help the study, the size of the study area makes it too small for feasible use. For the temperature and humidity maps, the data-loggers performed well allowing the interpolation to generate its maps in which we based our study. The precision of the data-logger records allowed monitoring constantly any change occurring in their positions at the mesocosm and associate them with the activities performed by the lizards. Yet, the interpolation only estimates the values between points and may not be completely representative to the reality. Certainly, a thermal camera would had replaced the dataloggers with advantage, allowing even higher precision, constant thermal conditions and able to determine the temperature of the lizards. Nonetheless, the budget, field view of the camera and placement the camera would bring some logistic problems. Certainly all these techniques permitted the integration of ecologically relevant elements into a spatial context in such a way not yet much explored. This multidisciplinary approach leads to a more complete and realistic vision of animal behaviours under spatially and temporally variable ecological contexts.

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