Environmental conditions of dry stone walls’ wildlife

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Resum

Les parets de pedra seca són conegudes per ser un notable promotor de biodiversitat en àrees antropitzades. També es creu que podrien tenir certes condicions internes que les fan un habitat ideal per a la fauna més petita. Aquest estudi està emmarcat en un projecte major, conegut com a PECT, amb l'objectiu d'intentar descobrir si aquestes construccions realment presenten condicions interiors diferents a les de l'ambient extern, i com aquestes condicions afecten al comportament dels seus habitants. S'ha hipotetitzat com les diferències tèrmiques que hi podria haver amb l'exterior serien un clar indicador d'un possible efecte tampó, oferint, alhora, un punt de descans òptim per als reguladors ectoterms. Per demostrar-ho, s'ha dut a terme monitoreig al camp amb dispositius enregistradors de temperatures externes, durant un mes per cada estació de l'any. L'àrea d'estudi està localitzada entremig dels dos pobles Llers i Avinyonet de Puigventós, situats a Catalunya, Espanya. Es van distribuir deu llocs d'estudi diferents dins del perímetre de l'àrea d'estudi, on a cada un d'ells es va seleccionar una secció de mur on es van col·locar quatre dispositius en posicions diferents: a dalt del mur, a la cara nord, a la cara sud, i al terra de davant de la cara sud. Un cop tota la informació es va haver recollit, les dades obtingudes van ser ordenades i representades en diferents tipus de figures. Aquestes mateixes dades també es van fer servir per crear un model simulat per cada posició i cada estació, en base a la temperature del cos d'un llangardaix hipotètic, amb l'ajuda del paquet de dades per R 'NicheMap'. Finalment, es van obtenir quatre escenaris per cada estació al llarg d'un dia promig. El resultat per a cada un de les situacions va anar canviant en funció de les temperatures externes i la temperatura del cos del llangardaix. Mentre que en l'escenari d'hivern l'individu no va canviar de posició, en les altres tres estacions es va veure clar com l'animal tendia a buscar el millor lloc per cada hora del dia. Aquests resultats, d'acord amb evidències prèvies, senyalarien la presència d'un factor beneficial dins els microhàbitats de les parets de pedra seca. Encara que altres factors decisius no es tinguessin en compte, l'objectiu principal d'aquest treball s'ha pogut complir, mostrant com les condicions ambientals internes d'aquests murs poden ser un refugi per a la fauna petita.

Resumen

Las paredes de piedra seca son conocidas por ser un notable promotor de biodiversidad en áreas antropizadas. También se cree que podrían tener ciertas condiciones internas que les hacen un hábitat ideal para la fauna más pequeña. Este estudio está enmarcado en un proyecto mayor, conocido como PECT, con el objetivo de intentar descubrir si estas construcciones realmente presentan condiciones interiores diferentes a las del ambiente externo, y cómo estas condiciones afectan al comportamiento de sus habitantes. Se ha hipotetizado cómo las diferencias térmicas que podrían existir con el exterior serían un claro indicador de un posible efecto tampón, ofreciendo, a su vez, un punto de descanso óptimo para los reguladores ectotermos. Para demostrarlo, se ha realizado un monitoreo en el campo con dispositivos que graban las temperaturas externas, durante un mes por cada estación del año. El área de estudio está localizada en medio de los dos pueblos Llers y Avinyonet de Puigventós, situados en Cataluña, España. Se distribuyeron diez puestos de estudio distintos dentro del perímetro del área de estudio, donde en cada uno de ellos se seleccionó una sección de muro donde se colocaron cuatro dispositivos en posiciones diferentes: arriba del muro, en la cara norte, en la cara sur, y en el suelo de enfrente de la cara sur. Una vez toda la información fue recogida, los datos obtenidos se ordenaron y representaron en diferentes tipologías de figuras. Estos mismos datos también se utilizaron para crear un modelo simulado para cada posición y cada estación, en base a la temperatura del cuerpo de un lagarto hipotético, con la ayuda del paquete de datos para R ‘NicheMap’. Por último, se obtuvieron cuatro escenarios por cada estación a lo largo de un día promedio. El resultado para cada una de las situaciones va cambiando en función de las temperaturas externas y la temperatura del cuerpo del lagarto. Mientras que en el escenario de invierno el individuo no cambió de posición, en las otras tres estaciones se vio claro cómo el animal tendía a buscar el mejor sitio por cada hora del día. Estos resultados, de acuerdo con evidencias previas, indicarían la presencia de un factor beneficial en los microhábitats de las paredes de piedra seca. Aunque otros factores decisivos no se tuvieron en cuenta, el objetivo principal de este trabajo se ha podido cumplir, pudiendo demostrar cómo las condiciones ambientales internas de estos muros pueden ser un refugio para la fauna pequeña.

Abstract

Dry stone walls are known to be notorious biodiversity promoters in anthropic areas. They are also believed to offer certain internal conditions that make them ideal habitats for small wildlife. This is a study framed in a larger project, known as PECT, with the aim of attempting to discover if these constructions present different inner conditions from the environment, and how they affect its inhabitants. It has been hypothesized that such thermal differences would act as a buffer, and, in turn, grant an optimal resting spot for ectotherm regulators. In order to prove it, field monitoring with external temperature recording devices was done for one month for every season. The study area was located between the two terms Llers and Avinyonet de Puigventós, from Catalunya, Spain. Inside this area, there were ten different study sites, where a section of dry stone wall was selected to host four different recording devices: on top of the wall, on the north face, on the south face, and on the ground in front of the south face. Once all the information was gathered, the obtained data was sorted and represented in different figures. This data was also used to create a simulated model for each position and each season on the body temperature evolution of an hypothetical lizard, with the help of the R package ‘NicheMap’. Finally, four optimal scenarios for every season through an average day were made. The outcome of each situation shifted in accordance with the external temperatures and the body temperature of the lizard. While in the winter scene the subject didn’t change at all, in the other three seasons it was clear how it searched for the best spot throughout different hours of the day. These results, combined with previous evidence, would point towards a beneficial factor found in dry stone walls’ microhabitats. Even if other decisive factors were not taken into account, the end goal of this work was accomplished, demonstrating how these walls' inner conditions can be a refuge for small wildlife.

Thoughts about ethics, sustainability and gender perspective

Ethics:

This work serves a scientific purpose and is funded to raise awareness of our country's world heritage using modern research tools. The methodology employed has its strengths and weaknesses in line with scientific ethics.

We utilized non-invasive tools, known as IButtons[1], which are small metal devices measuring 2 cm², used to record temperature and humidity. These long-lasting chips operate on internal batteries, which consume very little energy compared to similar devices.

However, there are also some aspects that could have been improved. During fieldwork, for example, a part of our team had to trespass on private property, compromising ethics for efficiency.

Even if a part of our team had to prioritize time over ethics in this regard, I still think that we ensured the best ethical use and disposal of equipment we could in our methodology.

[1] MCI electronics. *IButton: What's an iButton?*
Retrieved 12th of May 2023 from: https://ibutton.cl/que-es-ibutton/

Sustainability:

The study involved computer work, which, despite its energy source, is preferable to more machinery-intensive field work. Most of our time was spent walking, which helped us minimize energy consumption. We also used phones sparingly for navigation, and recording devices that as stated above, are pretty much energy-efficient.

Regarding the mobility aspect, for a single trip of 52 km to our destination, multiplied by two (round trip) and four (for each season), we traveled a total of 416 km. This resulted in an estimated CO_2 emission of 0.102 t, very similar to the average EU citizen's during four days of the year (0,092 t)[2].

In my opinion, we prioritized minimizing pollution and preserving habitat sustainability as best as we could, despite the necessity of using a private vehicle.

[2] Myclimate.org: shape our future. *CO2 emissions calculator for your car.*
Retrieved 29th of June 2023 from: https://co2.myclimate.org/en/portfolios?calculation_id=5938535

Gender:

Gender is a complex and evolving topic, often accompanied by unfair conditions and stereotypes.

In this paper, the male-to-female author ratio for cited studies is 3:1. And even if it is not really possible to know 100% the gender of every person just by doing a small search on Google, it can be pretty much assumed that women today are a minority in the biology research field.

This scenario raises several hypotheses about certain obstacles that could hinder female participation. These obstacles may manifest as barriers to career advancement or as an accumulation of restrictive actions, like microaggressions and stereotypes, which can lead to mental health challenges.

However, I think society is becoming more self-aware, gradually identifying these barriers and providing support. Progress is slowly being made, but there is still a long way to go.

CONTENTS

1. INTRODUCTION

1.1. Dry stone walls

Dry stone can be understood as a building technique, whereas natural non-polished stones are piled up and used for the construction of walls (see figure 1), without any kind of adhesive subtract in between building blocks (Enciclopedia.cat, 2023). This technique has its origins in Europe's working fields, hundreds of years ago and back to the Prehistoric Age (UNESCO, 2018); when farmers started to give a certain usage to the rocks they removed from the soil while preparing their orchards for the proper cropping of an area. All the rocks and stones obtained after each till would be piled up and organized in the shape of a wall, helping to create safe spaces for harvesting, while defining every field’s range and facilitating the management of slope dynamics (Tarolli *et al.*, 2014).

Fig. 1. Photography of a dry stone wall construction in Llers, Catalonia. Own source.

How they affect slope dynamics and help mitigating erosion has also been studied. Some papers, such as Camera *et al.*, (2018) reviewed how the abandonment of walls can increase erosion rates and downstream sedimentation. Other works like Agnoletti *et al.*, (2015) suggest the materials of dry stone walls could be a key factor to prevent erosion and hydrogeological instability.

The effect of neglect and abandonment of the walls has also been studied, Petanidou *et al.*, (2008) discovered in a long term study that the maintenance of these constructions was related to the cultivation of their fields. If the increase in walls built and maintained was significant, there would also be a positive response regarding agriculture. However, if the stone walls were exposed to abandonment and were influenced by wildlife, they would start to suffer damage, and in turn collapse, leading to dangerous mass movements and landslides, sometimes leading to long term land degradation (Tarolli *et al.*, 2014).

In Europe, dry stone is considered an important feature of the landscape. It was during 2018 that UNESCO decided to recognize the art of building with dry stone as a world heritage term, and therefore make it part of UNESCO's list of intangible cultural heritage for humanity.

In Catalonia, the art of dry stone is also protected by other entities like the Landscape Observatory of Catalonia, which not only protects the monuments with laws, but also discloses them to the population and maps their layout, as seen in figure 2.

Fig. 2. Map showing the density of dry stone construction in Catalonia, Spain. Source: Landscape Observatory of Catalonia

Although dry stone walls have a strong heritage in Europe, they have also been found in other places all around the world. While some of them have been discovered on the American continent (Sandor *et al.*, 1990), others were constructed and persist in some regions of Africa (Cirikure *et al.*, 2015) and Asia (Lundholm, 2011).

Pretty much everywhere in the world where human culture could be found, dry stone walls were there, leaving a footprint through time of the anthropic influence over a territory. But not only is their appearance an indicator of human presence, they are also geological mirrors of all the bedrock and glacial drift materials that lie beneath them (Conservationhandbooks.com, 2023). Furthermore, they are also considered biological mirrors, as the biodiversity that can be found amongst them is a major hint of all the artificial interactions with the territory that took place over the centuries. That's why they can be compared to ancient mirrors, mirrors that reflect the accumulated impact of all the anthropic actions on the land in the form of biodiversity, and therefore their importance as natural selection's agents (Manenti, 2014).

1.2. Environmental conditions and how they change in a Mediterranean habitat

As it has been said, dry stone walls can be found all over the world, in many different climates and habitats, pretty much anywhere where there are fields and people with knowledge on the matter. However, this study shall focus only on the walls of the north-east region of Catalonia, because that's the place in which the experiment was conducted.

The north-east of Catalonia is formed by a very different cast of habitats, but most of them derive from the Mediterranean climate, which also defines them. Environmental conditions in such habitats are well studied, and even though they are known to depend on a long array of factors, such as the wind, the seasons, the rain, cloud coverage, etc.; the set of characteristics of these factors in a Mediterranean climate tends to repeat in a predictable fashion. This is why nowadays this climate can be safely defined by two main characteristics, its wet winters and its warm dry summers (Lionello *et al.*, 2006).

Considering all these conditions that define the Mediterranean climate, there can also be a stricter set of conditions for a more particular habitat, mainly found in Mediterranean basins, known as garrigue or scrubland (as seen in figure 3). Although this term more often than not refers to a vegetal community, it can also be used to describe its habitat, which was the main area monitored in this study. It is known that semiarid habitats such as these tend to be strongly bound with each season's characteristic weather, leading to a very hydrologically unstable behavior during wet seasons and a more stable behavior during dry seasons. A behavior that can, from time to time, propel some negative ecological impacts, such as wildfires.

Seasonal dependency is also related to seasonal fluctuations regarding determinant factors like infiltration capacity, which tends to regulate all of the ecosystem, including the flora and fauna of an area (Cerdà, 1997).

Fig. 3. Picture of a common type scrubland found in Catalonia. Own source

1.3. Microhabitats and biodiversity

Anthropic constructions such as dry stone walls not only have a cultural and visual impact, but they can also change the biodiversity of an area. If the little gaps between the materials of a small fraction of a wall are given enough importance, visualizing all of the microhabitats that these places hide is now much easier. Therefore, if all the lengths of each wall are summed up, the number of habitats that favor biodiversity suddenly skyrockets to an ever-increasing value.

Microhabitats such as the ones mentioned above are defined by their own environmental characteristics, leading to a predictable set of climatic features known as microclimates. These sets are usually composed of classic variables, like radiation, temperature, wind speed, etc. They are all variables that are used to describe the state of the atmosphere (Brooks *et al.*, 2008). By knowing the values of all these climatic factors, informatic models (such as the one seen in figure 4) can be created to simulate their spatial conditions and how they change over time.

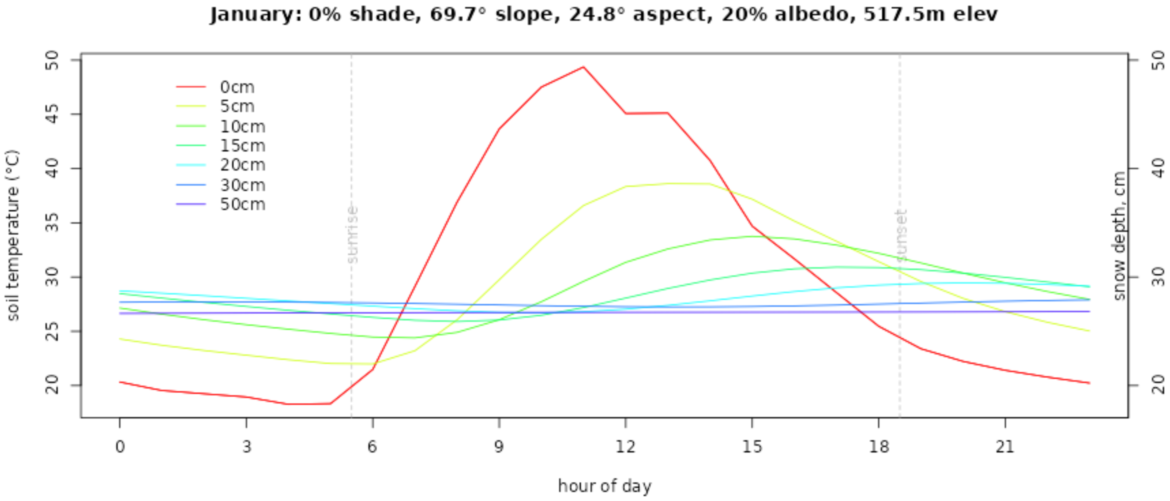

Fig. 4. Example of a soil temperature model on how the simulated conditions in a microclimate change through time, for the location -25,34, 131,04. Source: NicheMap Microclimate Shiny app

Depending on the metabolism of its inhabitants, these microclimates can offer them refuge during harsh seasons; and even some other advantages, such as easier nourishment, hydration, and healing. Thus, many new niches end up being created and renewed, niches that in turn fuel the specialization of its inhabitants.

In general, they tend to be small-sized and well-adapted in moving between narrow spaces, varying from reptiles to small mammals (Pascual, 2021). They represent a big fraction of the total biodiversity these stone walls fuel, and in many studies it has been researched its correlation. Iin some of them, such as Tanadini *et al.* (2012) it was seen how walls near the roads can create safe places for local fauna; meanwhile in others, it has been seen how they can outperform concrete walls and natural rocky walls in local biodiversity levels (Manenti, 2014).

These constructions however, do not only favor small wildlife and provide them with microhabitats, but they also promote biodiversity on a much larger scale, where all of the other habitants that live near dry stone walls can also be included. In more recent studies, such as Assandri *et al.* (2018) it has been confirmed that they do, in fact, present a positive correlation with some bird species.

1.4. Thermoregulation in small ectotherms: lizards as models

The metabolism of small animals can change a lot if it is compared to a middle-sized animal. There's not only a difference in energy consumption, but also a difference in the ways to obtain and store such energy, in the ways to maintain it, and in the ways in which all of these strategies shape the organism's body.

Reptiles, also known as *reptilia* or *sauropsida*, are the group this study will primarily focus on. They are one of the main taxonomic classes of the animalia kingdom, a class that’s formed both by anapsids and diapsids (birds). They all share in common a scale covered skin, shedded by some of them; appendixes with long claws or thin membranes and enhanced vision. They can be found in all sizes and different habitats, like marine, freshwater, and terrestrial ecosystems, and can even thrive in extreme conditions. Most of them are specialists with great adaptive strategies, that’s why so many of them tend to search for specific microhabitats and can be found inside all kinds of orifices.

The expected type of reptile that tends to be found in microhabitats are lizards, reptiles that, like the rest of them are known ectotherm regulators. While its body temperature may change daily, seasonally, and between different sexes (in a population level), their water retention levels seem only to change in relation to altitude, which tends to be higher on highland lizards, lizards that usually are subjected to more hard and fluctuating conditions, and thus are more specialized in searching for specific microhabitats (Sannolo *et al.,* 2020). Reptiles that live in places like these have also been proven to have the capacity to occupy different niches (Sillero *et al.,* 2020).

It has been demonstrated that not only does their thermal physiology dictate where they can be found, but also their hydrological one (S’khifa *et al.,* 2020). In many cases, is their own metabolism that makes them highly vulnerable to dehydration, which in turn also affects thermoregulation very negatively, forcing them to seek shelter in harsh climate conditions (Sannolo & Carretero 2019), such as those that can be found in the Mediterranean scrubland.

1.5. PECT Project

It’s very important to highlight that this study is part of a larger research and transfer project, which is also the main motivation behind its development, along with the lack of data regarding dry stone walls (Collier, 2013).

The project is titled “Innovació per a la valorització del patrimoni de la pedra seca.” (Ref. PR15-019070) funded by the Generalitat de Catalunya and Diputació de Girona in the frame of PECT, also known as “Projectes d’Especialització i Competitivitat Territorial”. The project is led by the University of Girona with the participation of other organizations, including Consell Comarcal de l’Alt Empordà. The main group leading the action on ‘Biodiversity of the dry stone heritage’, is the Animal Biology department, with Dr. Pere Pons as principal researcher and Dr. Marc Franch as postdoctoral researcher.

2. OBJECTIVES

The main objective of this study is **to explore possibilities of small animal behavior based on temperature models related to dry stone structures**. The specific objectives that derive from it are:

1. To describe the daily temperature variation in different microhabitats associated with dry stone structures and out of them, during the four year seasons based on temperature monitoring in field stations.
2. To produce a model of animal behavior based on body temperature using lizards as a model of small ectothermic vertebrates.
3. To relate the temporal trends of the temperature in dry stone ecosystems to the model of animal behavior.
4. To infer the benefits of different microhabitats and times of dry stone structures as thermal refuges and places that increase animal activity.

Considering all of the facts displayed above, the obtained results would be expected to show some kind of response by the lizard’s body temperatures in relation to the external temperature models.

For example, when the environment tends to be dryer (hotter temperatures), the lizard may try to seek refuge in a more humid place, and when the temperatures rise too much or drop too much, it might also end in the same result. Even though it might be expected from the lizard to seek a colder refuge when the temperatures are hot (north face of the wall), and a warmer refuge when the temperatures are low (south face of the wall). And maybe the more extreme places, like the top of the wall or its surroundings, are not so extreme during some specific hours, allowing lizards to bask or hunt on them. Similarly, it is expected of the two faces of the wall to act as a smoothing agent of extreme environmental conditions, and, in turn, act as what is known as a buffer.

3. METHODOLOGY

3.1. Area of study

As previously stated in section 1.2., the main habitat where this study takes place are the so called mediterranean scrublands located in the nort-east region of Catalonia. The section monitored during the experiment is situated within two municipal terms: Llers and Avinyonet de Puigventós (Fig. 5).

Fig. 5. Map of the main municipal terms where the study takes place. Own source.

A study area was defined to properly study the temperature effects of the Mediterranean environment while gathering all the necessary data to do so.
As it can be seen in figure 6, the perimeter of the study zone is highlighted in red, while the study sites chosen for recording temperature and humidity are shown inside the perimeter, in green.

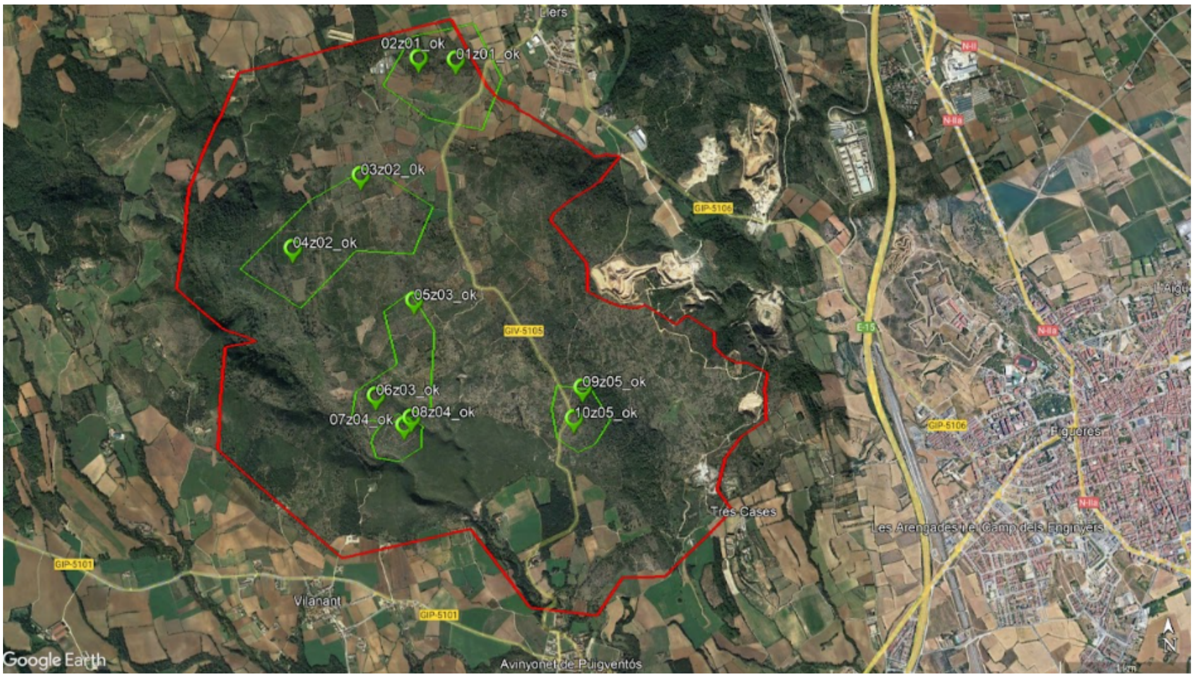

Fig. 6. Study area and recording points. Own source.

There was a selection of 10 study sites separated by at least 500 m from each other. Each site consisted of an average 30 m long section of a well-preserved wall and its immediately surrounding natural habitat (Fig. 9).

In figures 7 and 8 it can be appreciated how the local flora is composed mainly of pines and typical Mediterranean gymnosperm trees, while its undergrowth is mainly populated by rainfed and dryland plants.

Figs. 7 and 8. Pictures of the study zone's vegetation cover. Own source

3.2. Temperature and humidity monitoring

The main tool used for all the monitoring processes and data harvesting has been a small circular metal chip known as IButton (patented by Dallas Semiconductors) which is capable of recording humidity and temperature values for prolonged periods of time. IButtons can be programmed to be set for a specific date on which they can start gathering all these values, and registering them every 30 minutes. In other studies, such as Fawcett *et al.,* (2019) there's a further explanation of their usage.

Four of these devices were installed in each study site. They were placed in four different positions in relation to the stone wall (Figure 9).

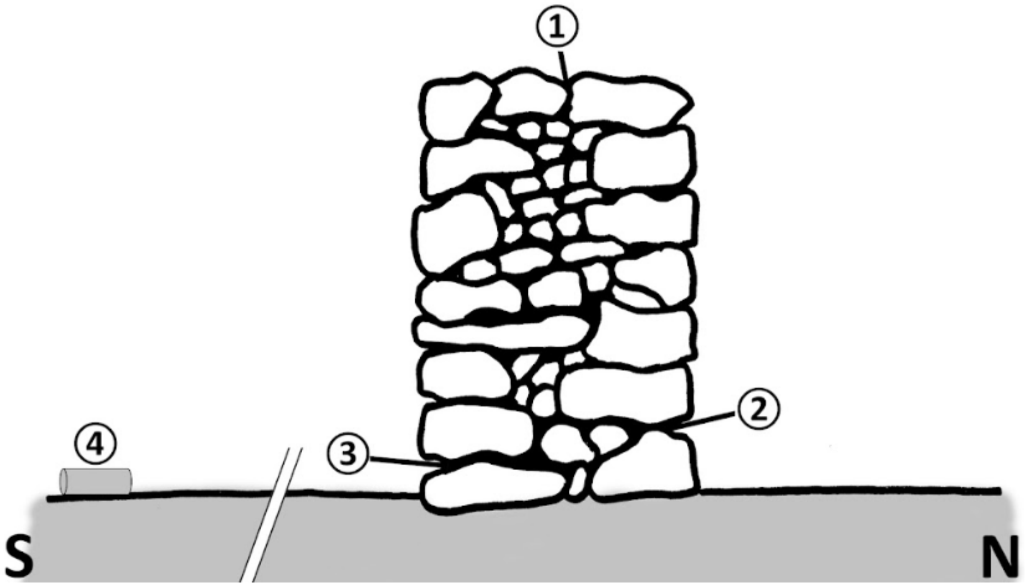

Fig. 9. Scheme of the different positions where the iButtons were placed. Own source

The numbers in figure 9 correspond to: 1. On top of the wall (TOP), 2. In its northern face (NOR), 3. In its southern face (SOU), and 4. On the ground in front of the wall's south face (GRO).

3.3. Data treatment

While the main tool for data processing was Excel, the tool used for graphic generation was RStudio.

For data processing, the first step was to download all the information from each iButton, store it, and sort it. Even though each iButton gave out information both for temperature and humidity, it was decided to only take temperature values based on the objectives displayed earlier in this work. To follow up, the different values of each day's temperature were rearranged based on time and plot (position of the iButton), obtaining its average value for each thirty minutes in four different plots, accompanied by the standard deviation value.

Once the data processing and organization were finished, only the graphics elaboration remained, which was done with the 'NicheMapR' package for RStudio (see download in NicheMap's home page) and all the commands included in its tutorial.

The resulting graphics were divided into two different sets, in relation to the type of information they gave out.

The plots in the first set (figure 11) were made using Google Spreadsheets' linear charts tool. They show how temperature (on the y axis, in celsius degrees) evolves, for every different position of the wall through time (on the x axis, in days)

The second set of charts has more information, including the body temperature of the lizard, air temperature, critical thermal maximum, and many more. It represents how the simulated body temperature changes depending on the air temperature (both on the y axis, in degrees Celsius) through one month of a season (on the x axis, in days).

In order to simulate each wall's conditions as accurately as possible, the pre-established values of the parameter "TALOC" (Local Air Temperature) were exchanged with the ones registered in the field work.
But, because of not gathering enough samples to cover the three months that form a season, it is assumed within every following chart that the temperatures of each month during a season are always the same, this is why it is shown only one month for each season.

The parameter "maxshade" corresponding to the maximum shade of vegetation or other objects, was also changed depending on the position. For position TOP the value was set to 10%, as at the top of the wall there was practically no shade except for the little rocks found there. For NOR and SOU the value was set at 100% as the temperatures were recorded inside the walls. And finally, for GRO the maximum shade was assumed to be 50%, as in some places there were lots of trees but in some others there weren't many.

All the other microclimate type data used in the second set of charts comes from world meteorological data banks found on the NicheMap home page, which have been properly set to take data exclusively from a geographical point within the study area (42.276377, 2.901836).

Meanwhile, the model lizard used was*Timon lepidus*, as it is one of the largest among the Mediterranean wall lizards. According to the species characteristics, its weight would correspond to an average of 500 g for an adult (Biotropics, 2015). All the other parameters related to the lizard were the default ones from the trans behavior shiny app.

Practically all the R codes used to generate the charts have been extracted from the *trans_behav* budget model found in its corresponding github page. This model is a variation of the ectotherm model, which is able to, in the words of Kearney *et al.* (2021), "compute the thermoregulatory behavior of an organism in a time-varying thermal environment as it shuttles between shade and sun".

Data from the ectotherm model shiny app (Kearney & Porter 2019), and the Ectotherm Transient Thermoregulation Model (Kearney *et al.,* 2021) was also used to create the thermoregulation plots.

4. RESULTS

After following the elaboration process explained above, two sets of different graphics were created.

There will be a legend before or within every important figure generated in these results, said legend will contain the necessary symbology to understand the charts, and if it’s needed, it will come with specifications on how to interpret them accordingly.

The symbology for the first set is represented in the figure below.

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Fig. 10. Symbology for the first set of graphics (figure 11).

In the first set, there will also be two different deviations, the upward one (on top of the average) and the downward one (below the average), which will always accompany the average.

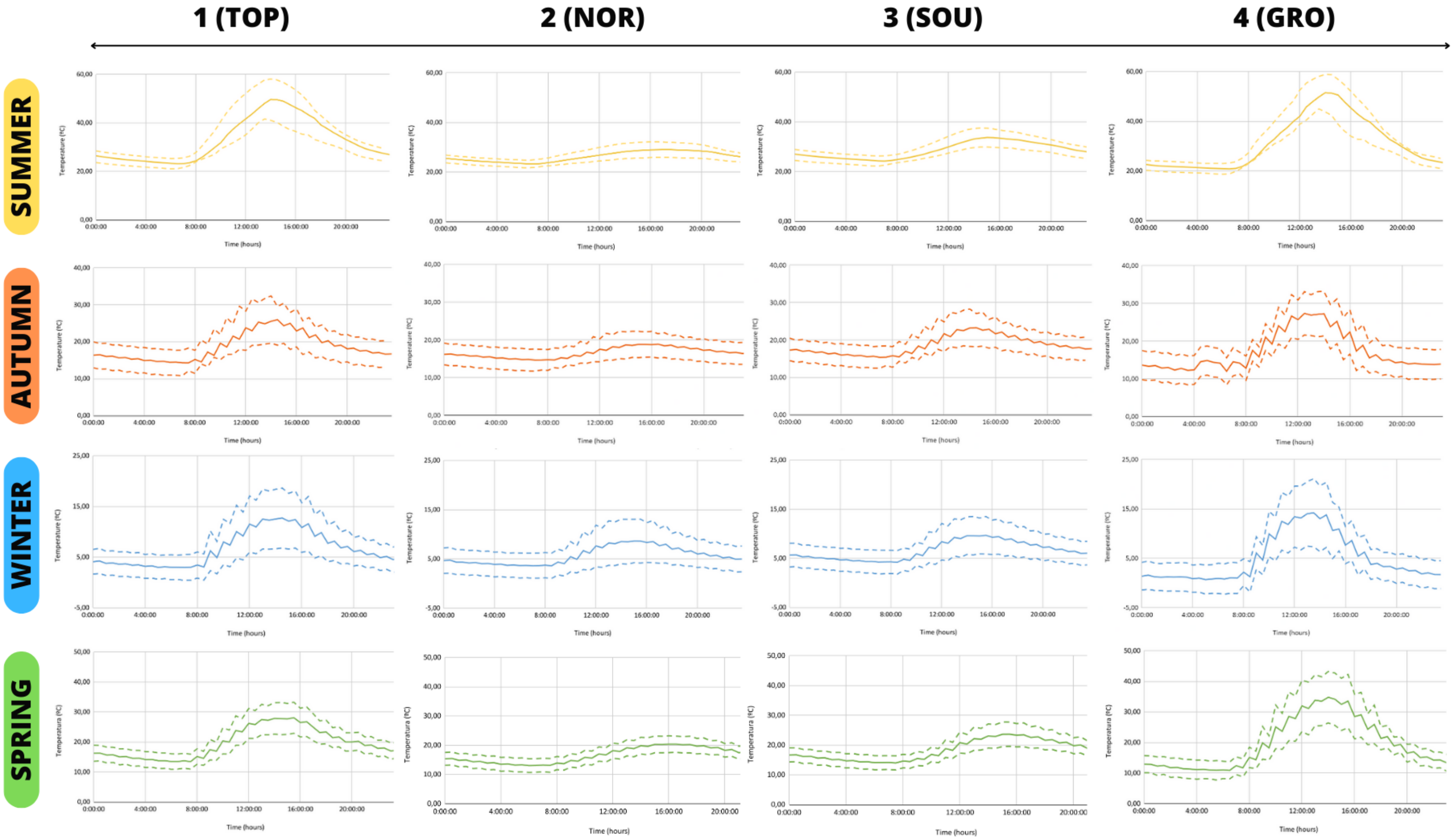

Fig. 11. Temperature evolution on the four different positions of the wall (top) through an average day of every season (left).

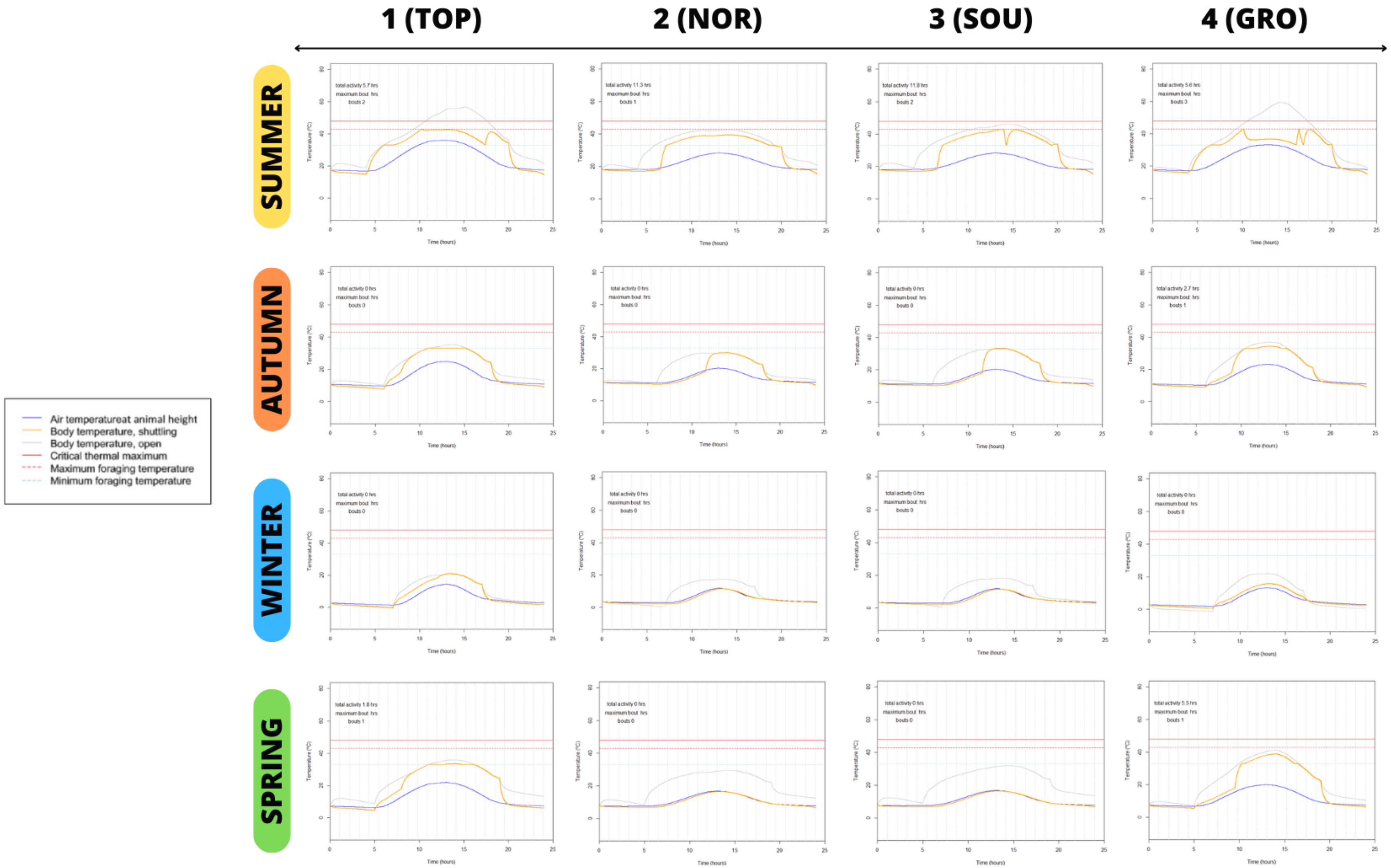

Fig. 12. Body temperature evolution of a simulated lizard on the four different positions of the wall (top) through one day of an average month of every season (left).

The second legend's items can lead to some misinterpretations, so here's a brief clarification:

- "Air temperature" refers to the temperature of the shaded air.
- "Shuttling" refers to body temperature when shuttling between shade and sun.
- "Open" refers to body temperature when found only in the open sky.

While the first set of charts in figure 11 shows how the temperature of a specific location changes through time, and therefore makes the environment more or less hostile, the set seen in figure 12 makes it clear how these variations of the temperature through time affect the environment's inhabitants.

Based on all the information that they offer (which will be further elaborated in the discussion section), a final model of how its hypothetical life would react to those changes in the search for an optimal environment can be created.

The criteria that were established to make the models is the following:

1. There will only be four possible locations where the simulated lizard can move (see figure 9).
2. The optimal position will always be the one described by the shuttling body temperature line.
3. When the shuttling body temperature line is not between the two foraging limits, the lizard will be resting. When the shuttling body temperature is the same as the air temperature or lower, it will be assumed that the optimal position is the default one.
    3.1. The default optimal position will be SOU during fall, winter, and spring, and NOR during summer.

    This is because wall lizards prefer rocky surfaces over ground terrain (Arnold & Ovenden, 2002).

    In addition, based on how external factors affect each wall's face depending on the orientation (Khavrus & Gabovich, 2022), it will be assumed that during fall, winter and spring, the SOU face has a more favorable set of environmental conditions. The same will be assumed for the NOR position during the summer.
4. When the shuttling body temperature line is between the two foraging limits the lizard can now be foraging, basking, or hiding (it's active). In this case, the optimal chart will be the one where the shuttling body temperature has more bouts (it thermoregulates better than the others = more energy obtained while yielding the same).
    4.1. If the charts have the same number of bouts, then the one with the highest activity will be considered the optimal.

Based on this criteria the resulting table of optimal positions for every hour is the following:

Table. 1. Optimal positions assigned to each hour based on the stated criteria

Hour of the day	**Summer**	**Autumn**	**Winter**	**Spring**
	Position	Position	Position	Position
0	2	3	3	3
1	2	3	3	3
2	2	3	3	3
3	2	3	3	3
4	2	3	3	3
5	2	3	3	3
6	2	3	3	3
7	4*	3	3	3
8	4*	3	3	3
9	4*	4*	3	3
10	4*	4*	3	4*
11	4*	4*	3	4*
12	4*	4*	3	4*
13	4*	4*	3	4*
14	4*	4*	3	4*
15	4*	4*	3	4*
16	4*	3	3	4*
17	4*	3	3	4*
18	4*	3	3	3
19	4*	3	3	3
20	4*	3	3	3
21	2	3	3	3
22	2	3	3	3
23	2	3	3	3

*In these locations the lizard is in its optimal range of body temperature for foraging when shuttled.

With all the values obtained from comparing the charts and having them sorted out (table 1), now four motion-framed models can be made out of it, with its respective legend (Figure 13).

Fig. 13. Symbology for figures 14-17.

As pdfs don’t allow gifs without the use of special tools, below there will be a selection of the frames for the hours where the lizard’s position varies more between seasons. Even so, the gifs will be available for everyone interested in seeing them in the following drive folder: https://drive.google.com/drive/folders/1-50xo3tq3V8I8EgIu0tTcpyrOFAgmDyc?usp=sharing.

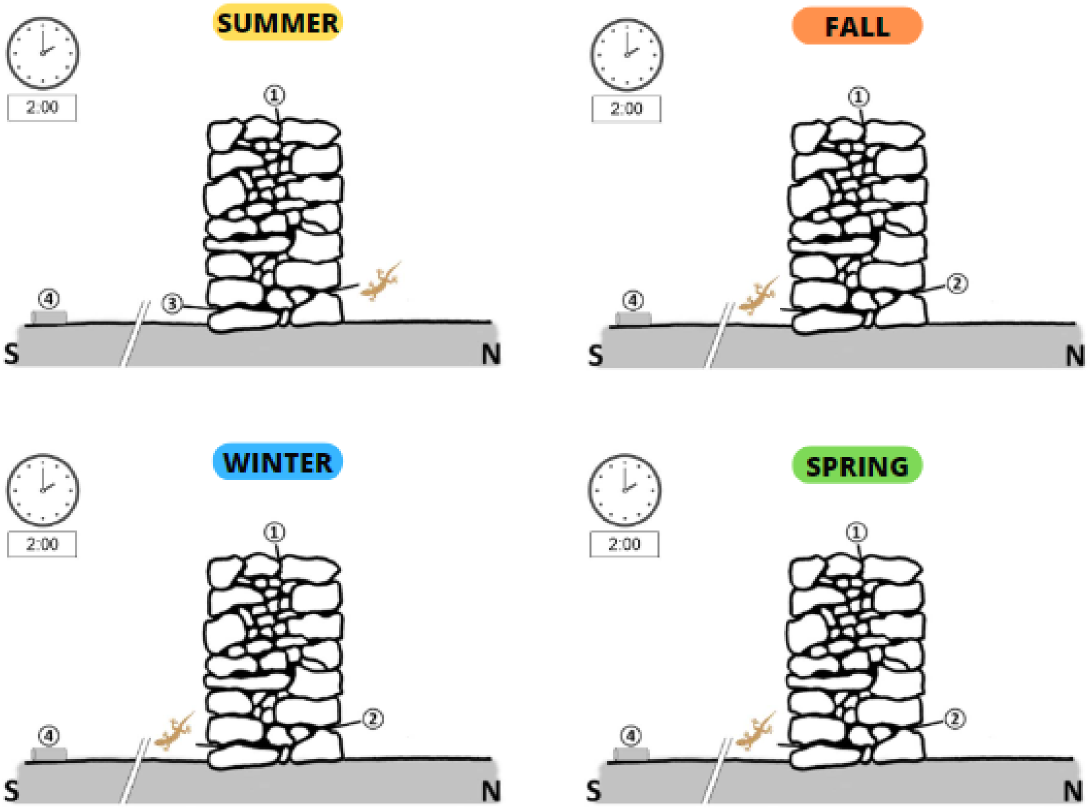

Fig. 14. Model of a lizard that searches the best spot on the four seasons at 2:00h

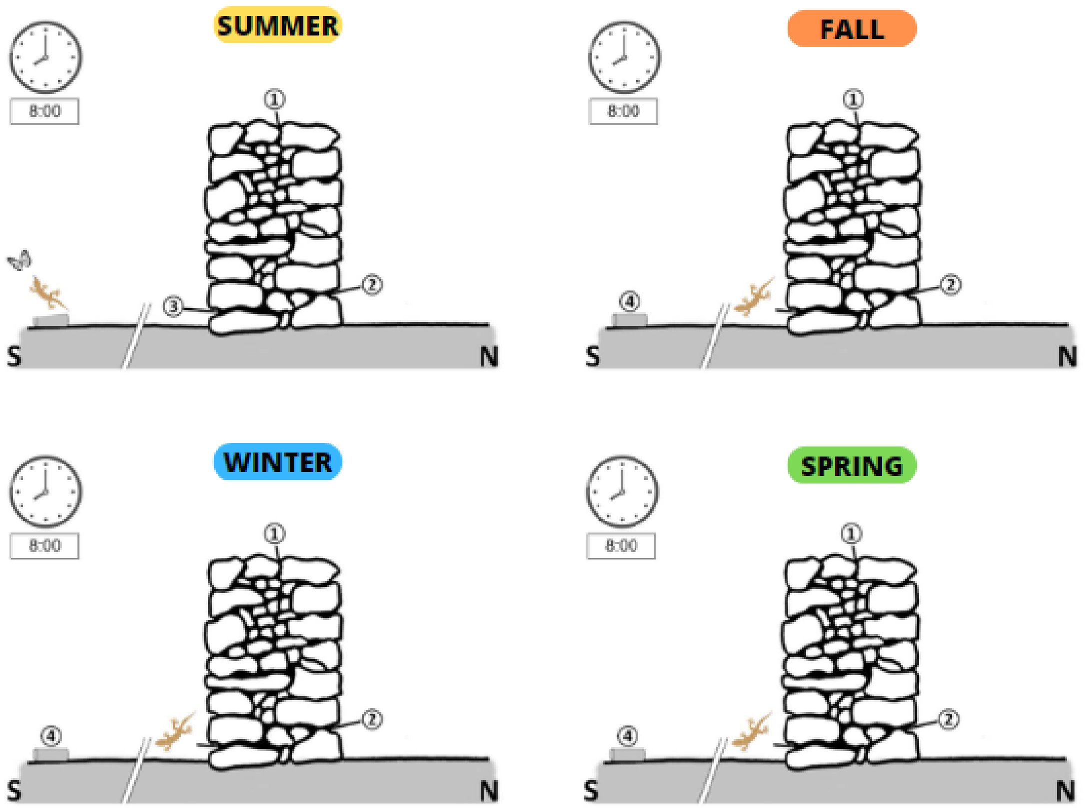

Fig. 15. Model of a lizard that searches the best spot on the four seasons at 8:00h

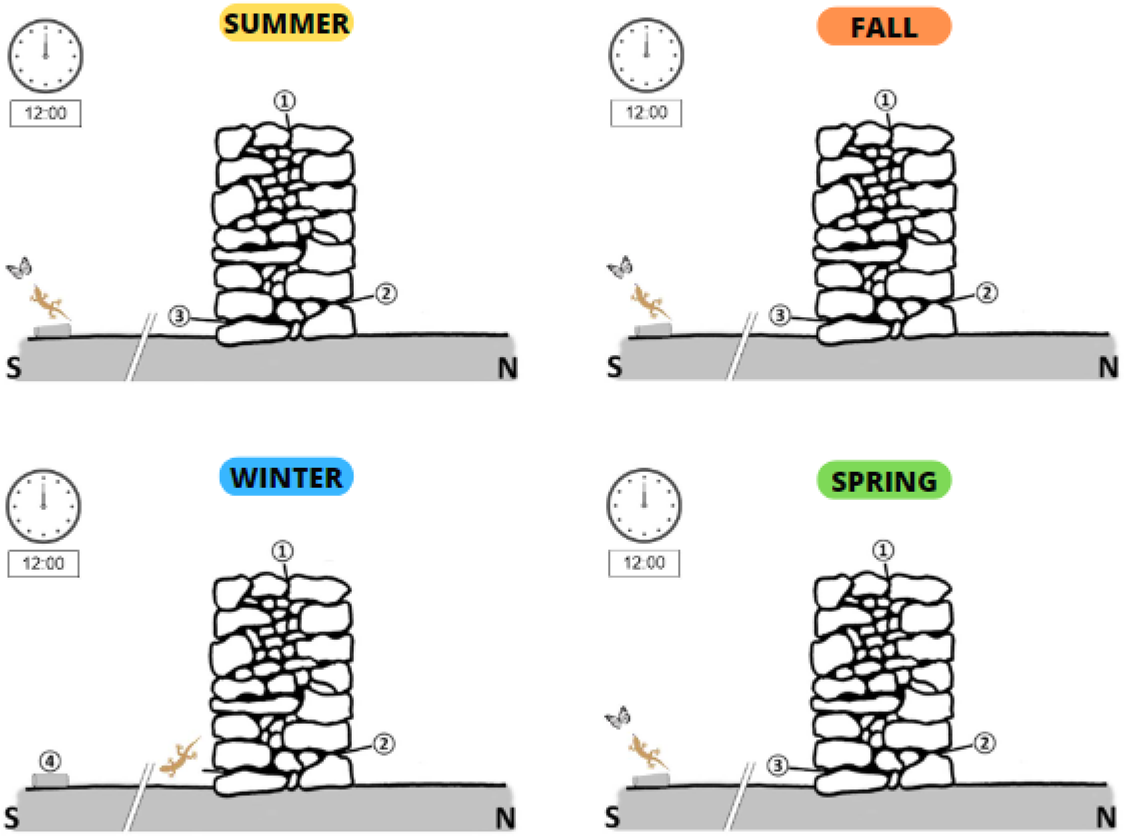

Fig. 16. Model of a lizard that searches the best spot on the four seasons at 12:00h

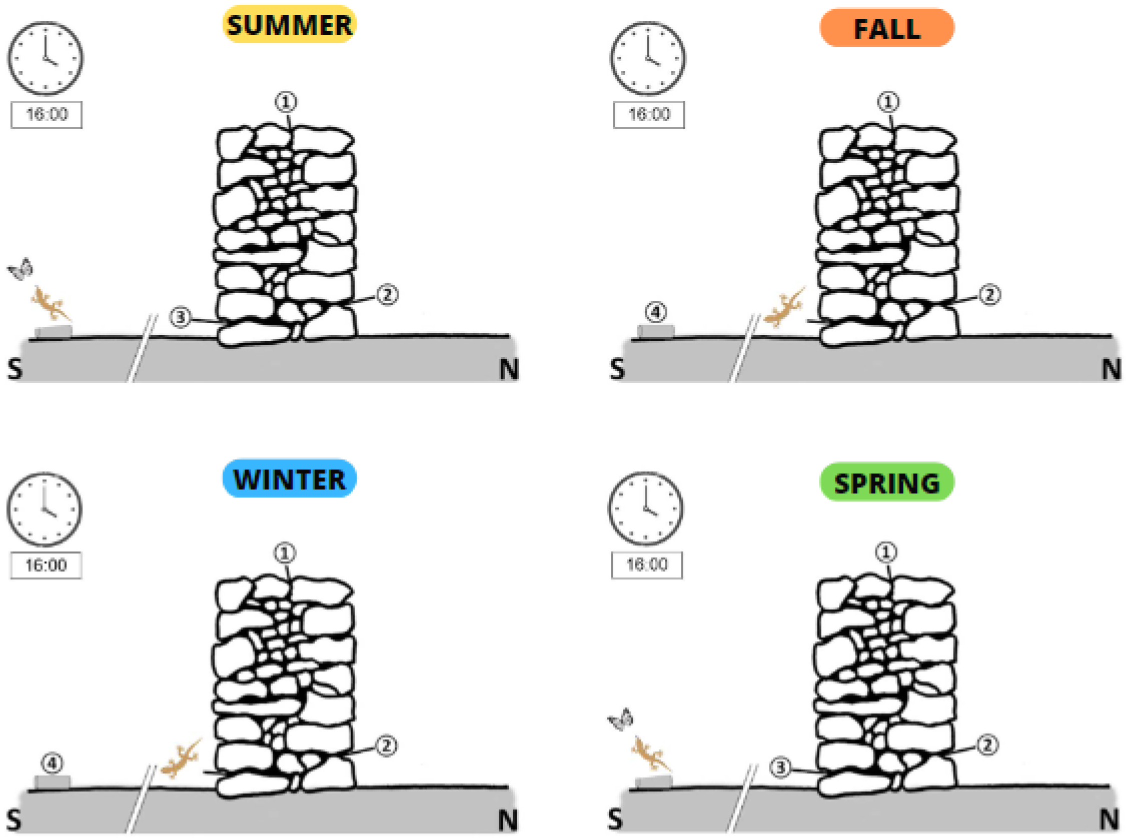

Fig. 17. Model of a lizard that searches the best spot on the four seasons at 16:00h

These models (figures 14-17) correspond to the most optimal position in which the fictional lizard would be found in a simulated case scenario at specific hours of the day.

Figure 14 doesn't have much secret, as during that time of the day (2 a.m.), the lizard in every position is resting inside one of both faces of the wall. The subject will always search for a place where it is least disturbed.

It's at 8 a.m. (figure 15) when there's some visible change. In search of the optimal spot, the lizard leaves the resting area and ventures into the terrain outside the wall, but only during the summer, as in spring, fall, and winter it is still too cold to risk going outside. As the day begins, the reptile during the summer starts its shuttling bouts in order to obtain the maximum benefit. Meanwhile in the winter, it stays indoors to maintain its temperature and lose as little energy as possible.

When midday arrives, at 12 a.m. (figure 16), the lizard has finally ventured outside in all of the frames, except in winter, where it stays inside maintaining its hibernation phase. In the three other seasons as the apex of the day sets, position 4 offers a better foraging ground than position 1, with more shade and more hiding spots that make it a suitable location for hunting.

Finally, it’s at 4 p.m. (figure 17) when the lizard in autumn goes back into its hiding spot due to the sudden drop in temperatures, in comparison to the summer and spring simulations, where the lizard keeps on foraging. In winter the subject is still stagnant.

5. DISCUSION

First of all, it’s important to note that a big part of the results did go as expected, as the temperature graphics (figure 11) had their highest heat peaks in positions 1 and 4, confirming the hypothesis that the most extreme places tend to have more extreme values. These peaks were also accompanied by wider deviations, which usually mean a larger range of values, and therefore more notorious differences between each replica.

There were also other details that gave out important pieces of information, like the difference in the represented ups and downs between the charts in figure 11. Some of these ups and downs had smoother transitions than others, especially the lines in positions 2 and 3.

As to why it took place, one reason could be the buffer effect, previously hypothesized in the objectives section. Both faces of the wall present a more sheltered space than the harsh emptiness of spaces 1 and 4, which in turn could end up smoothing the external temperature's influence.

If a closer look is taken at positions 2 and 3, it can also be seen how the temperatures in position 2 point to the north face as a much more perfect environmental buffer than the south face. Even the deviations are much closer to the average, and the evolution of the curve doesn’t change as much as the others.

Studies have shown that southern faces tend to dry faster as they are more exposed to sunlight than the northern ones (Marincioni & Altamirano, 2014), which could lead to the previously discussed effect. However, even if both faces are exposed to the same internal conditions, the external ones also play a major role in their temperature evolution. A statistical analysis and further research would be necessary to see the real importance of these external influences.

The second set of plots (figure 12), also displays more interesting information that must be discussed.

The season when the lizard is most active is the summer. Counting both the number of bouts and the total active hours, it’s in positions 3 and 4 where the lizard reaches its prime. While in the first plot it accomplishes a total of 11,8 hours of activity, in the second it is able to attempt shuttling bouts three different times from sun to shade, probably to cool down after every hunting attempt.

In other seasons, like winter there’s very little activity and no foraging behavior, confirming the slow metabolism response and hibernation habits of the model species described in

Tatin *et al.* (2013).,

During fall, the activity is also really low, but in some scenarios like the 4th location, there will be activity and shuttling bouts due to the midday rising temperatures, and even if they are not as warm as summer, they provide enough of a chance for the lizard to attempt foraging.

Same as in spring, as the temperatures still remain pretty cool. In the more extreme places, though, like positions 1 and 4, the midday temperatures are warm enough for the subject to venture into its shutting bout routine.

In a more general sense, the efficiency of the simulated model was really impressive. What made it stand was the representation of the external temperatures' effect on the animal's body. This can be seen when the two sets of graphics are compared, as the upward standard deviation line (in figure 11) is practically the same as the body temperature of the animal in the open sky (in light gray, figure 12). In some cases, like the plots that represent positions 2 and 3 (both faces of the wall), this parallelism between graphic sets seems to be less clear, as the two hypothetical body temperatures are way higher or lower than the upward deviation. A difference like that could be easily explained by the large number of other external factors, factors that were disregarded in this study in order to center only on the influence of temperature.

The four model gifs created from the previous graphics also show interesting outcomes that must be addressed.

Previous studies, like Rouag *et al.* (2006), point out the importance of sunshine for these types of lizards, which appear early in the morning in order to start basking. In the results (table 1), it is seen how in summer, fall, and spring the lizard emerges early in the morning, confirming its necessity for sunlight, even though it's at a different hour for every season, probably due to the differences in the photoperiod.

The fact that the lizard prefers the ground when hunting rather than the top of the wall, or the inner faces of the wall, stays in line with today's known *Timon lepida*'s preferences (Mateo, 2017). Position 4 also provides a more covered hunting ground than the others, as it has more space for running while maintaining many hiding spots at its disposal. Benefits like these make it optimal for hiding from its own hunters while foraging, an impossible scenario at the top of the wall, where the lizard would be too exposed to eagles, its main predators (Vlachos and Papageorgiou, 1994).

In this study, only temperature and its direct relation with the lizard have been studied, but it is known that this species distribution is also affected by many other variables (Kgosiesele, 2010). Some of the results could also be affected by these factors, for example, the number of active hours the lizard spends on a certain position. Deeper research, keeping in mind other environmental factors, would be necessary to obtain a more accurate prediction.

6. CONCLUSIONS

Field work and simulated scenarios with the collected data have been done in order to explore the possibilities of animal behavior in dry stone walls. The resulting models of these simulations proved to be functional, and gave an early approximation of such behavior.

It was also possible to describe the temperature patterns in dry stone walls for each season, while confirming some of the stated hypotheses in the beginning, the main one being the expected buffer effect. Inner walls proved to be efficient insulators for the external conditions, acting as temperature smoothers while creating a suitable microhabitat for small wildlife.

A model of animal behavior was created, and with the species *Timon lepida* as model, it was possible to determine the body temperature trends in each position of the wall for every season. Validating how winter forces the subject into an hibernation process, and how the lizard profits from the daily sunlight, during the other seasons, both for basking and foraging.

There was also confirmation on the efficiency of the chosen model, as the difference between the body temperature of the animal in the open, and the external recorded temperatures, was not much. And even though there was no analytical test to verify the model's accuracy, there seems to be more when the lizard is not sheltered.

Four different models were made that helped estimate the optimal position for the lizard through every season. Although the models only took into account the lizard's body temperature and the external temperature, the results were not so different from what was expected. It would be necessary to take into account other external (wind, humidity, terrain, …) and internal variables (species, distribution, sex, diet, …), to get a more accurate picture of what an optimal situation for the average dry stone wall inhabitant would look like.

The fourth specific objective was partially achieved, as there was no direct inference in the benefits of stone walls as thermal refuges. However, thanks to the gif models it could be illustrated how in all the cases, both faces of the wall were a much preferable spot for resting ground than the external terrain.

To conclude, there's still a lot of work to do in the field of dry stone, notably in the biodiversity aspect, where much research is lacking. This work only focused on one model which most of it was simulated, yet it has answered many questions, and raised some more, perhaps helping to pave an easier path for future studies ahead.

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