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CONTRIBUTIONS TO THE ECOLOGY OF AN ENDEMIC REPTILE OF CABO VERDE, *CHIONINIA VAILLANTII*

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Index

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BM   Body Mass

BMi   Initial Body Mass

CC   Climate Change

ESD   Education for Sustainable Development

EWL   Evaporative Water Loss

F   Non-pregnant Female

Fp   Pregnant Female

IUCN   International Union for Conservation of Nature

M   Male

PBL   Project Based-Learning

Q   Question

SVL   Snout-Vent Length

Ta   Abdominal Temperature

Th   Head Temperature

Tp   Body Temperature

Tt   Tail Temperature

RESUMO

O conhecimento da ecologia básica das espécies e a comunicação deste ao público e políticos é necessária para fomentar a conservação. Tal é especialmente urgente para endemismos insulares, mais susceptíveis à extinção do que os continentais. No entanto, répteis como *Chioninia vaillantii* – um escíncideo vivíparo, Em Perigo, endémico das ilhas cabo-verdianas, ameaçado por perseguição e alterações climáticas (AC) – são frequentemente ignorados em projectos de conservação.

Consequentemente, o objectivo desta tese foi aprender sobre a ecologia de *C. vaillantii* e promover a educação ambiental sobre a mesma. No manuscrito I (MI), as preferências térmicas, a influência da disponibilidade de água na termorregulação e a resposta fisiológica à baixa humidade desta foram experimentalmente estudadas. No manuscrito II (MII), o impacto da produção de um filme na percepção e atitudes dos estudantes sobre répteis foi avaliada com questionários, entrevistas e análises de conteúdo.

Resultados do MI demonstram que *C. vaillantii* selecciona temperaturas mais baixas que outro escíncideo menor e amplamente distribuído, *Chioninia delalandii*, mais elevadas até quando sem água. Tal explica a distribuição contrastante destas espécies e realça a vulnerabilidade da primeira às AC. Adicionalmente, demonstram que escíncideos grávidos apresentam respostas fisiológicas diferentes dos não-grávidos, provavelmente para proteger os embriões. Mais, o rácio superfície/volume foi importante para a perda hídrica a baixa humidade, mas a espécie pequena soube compensar comportamentalmente.

Resultados do MII mostram que a actividade de aprendizagem baseada em projecto aumentou significativamente acções e sentimentos positivos sobre os répteis e a percepção da importância de *C. vaillantii*. Essas alterações provavelmente estão relacionadas ao uso das tecnologias móveis e possivelmente ao aumento das ligações emocionais à espécie e aos resultados da actividade.

Concluindo, este estudo pode facilitar acções de conservação dos lagartos cabo-verdianos e a educação para a sustentabilidade e ser usado como modelo para outros répteis afectados por AC e perseguição.

ABSTRACT

Knowledge on species basic ecology and its communication to the public and policymakers are needed to promote conservation. This is especially urgent for island endemics, more susceptible than mainland ones to extinction. However, reptiles such as *Chioninia vaillantii* – a viviparous Endangered skink, endemic of Cabo Verde Islands, threatened by persecution and climate change (CC) – are often disregarded in conservation projects.

Hence, the objective of this thesis was to learn about *C. vaillantii's* ecology and to promote environmental education about it. In manuscript I (MI), its thermal preferences, the influence of water availability in thermoregulation, and its physiological responses to low humidity conditions were experimentally studied. In manuscript II (MII), the impact of a movie production on student's perceptions and attitudes towards reptiles was evaluated with questionnaires, interviews and content analyses.

Results of MI showed that *C. vaillantii* selected lower temperatures compared to another widely distributed and smaller skink, *Chioninia delalandii*, even higher when without water. This explained their contrasting ranges, and highlighted the vulnerability of the former to CC. Additionally, results showed that pregnant skinks presented different physiological responses than non-pregnant, probably to protect embryos. Moreover, that surface/volume ratio was important for water loss in low humidity conditions, but that the smaller species was able to compensate that behaviourally.

Results of MII showed that the project-based learning activity significantly increased positive feelings and actions of students towards reptiles, and the perceived importance of *C. vaillantii*. Those changes were probably related to the use of mobile technologies, to the selected method, and possibly to the increased emotional connections to the species and to the outputs of the activity.

In conclusion, this study may facilitate conservation actions of Cabo Verdean lizards and education for sustainability and be used a model for others reptiles affected by CC and persecution.

1. GENERAL INTRODUCTION

1.1 ECOLOGY, SCIENCE COMMUNICATION, AND CONSERVATION

Climate Change (CC), introduced species and habitat loss are the main threats to biodiversity (Brook et al., 2008; Sax & Gaines, 2003; Urban, 2015) which can lead to species extinction. Most of these threats are related with human actions, including climate disasters, and so many authors called this epoch as Anthropocene (Steffen et al., 2011). Abiotic factors, such as temperature, and extreme events, such as droughts, are some of the important components of CC that affect biodiversity (Bellard et al., 2012). The effects of these factors in some cases might be immediate, but it often takes time for declining populations to disappear following natural and anthropic perturbations (Kuussaari et al., 2009). Therefore, there is time to implement conservation measures, while a species that is predicted to become extinct persists (Barnosky et al., 2011; Kuussaari et al., 2009). To achieve a better sustainable management and conservation of wildlife we need to understand the basic information about the ecology of species, such as the underlying factors explaining it distribution and behaviour (Lawler et al., 2011; Sutherland, 1998).

At the same, time human actions are triggering species extinctions, almost half of the world population lives in urban areas and is increasingly disconnected from nature and biodiversity loss (Miller, 2005). And this is getting worse because children spend less time outdoors (Kahn Jr & Kellert, 2002; Miller, 2005). Physical contact and emotional links are very important to re-create this connection with nature (Lumber et al., 2017). To facilitate this connection between humans and nature, Education for Sustainable Development (ESD) and science communication are necessary. ESD combines guiding principles, knowledge, skills, perspectives, and values that include sustainability concepts and issues (Tilbury & Stevenson, 2002) while science communication main objective is to engage people in science (McKinnon & Vos, 2015). Science communication is also good to gain political and public support for conservation practices (Ogawa, 2012).

Ideally, biologists need not only to increase knowledge about the ecology of species but also to learn how to communicate their findings to people to promote conservation and reduce anthropogenic threats (Bickford et al., 2012). To communicate scientific knowledge to the public, biologists need to be more proactive and provocative in this area (Bickford et al., 2012). To become better communicators, biologists should take into account the cultural values, belief systems, and social networks that affect the perception of local people about science and nature (Bickford et al., 2012). Technology can also play an important role in conservation (Berger-Tal & Lahoz-Monfort, 2018). Increasingly, families and schools are investing in technology such as computers, internet,

and software (Herold, 2016). It is important to integrate new technologies into education for sustainability since it may offer new and powerful ways to engage students in ESD (Pilgrim et al., 2012). One way to engage students in ESD is using project-based learning (PBL) approaches (Almulla, 2020; Khandakar et al. 2020). PBL is a student-driven, teacher-facilitated approach to learning. Students pursue knowledge by asking questions that have arouse their natural curiosity (Bell, 2010). The main goal is to solve real-world problems by designing their own projects, planning their learning and researches, and implementing learning strategies (Bell, 2010).

1.2 ISLANDS AS PRIVILEGED MODELS

Islands are also important for conservation since they represent the greatest concentration of both biodiversity and species extinctions (Whittaker et al., 2017). Islands have around 20% of all terrestrial species in about 3.5% of the planet Earth land area (Whittaker et al., 2017) and present higher rates of endemism when compared to mainland areas (Kier et al., 2009). Island biotas are also particularly susceptible to extinction because they are more sensitive to environmental, climatic, and anthropogenic pressures (Manne et al., 1999; Wood et al., 2017). Reduced land area compared to mainland, dispersal barriers due to water masses among islands, and insular adaptations make islands biotas more sensitive to extinction (Wood et al., 2017). Additionally, islands are good models for ecological studies due to the generally high abundance of individuals, and their simplicity of habitats that eases the sampling and isolation of variables (Whittaker & Fernández-Palacios, 2007).

Oceanic islands are islands frequently formed by volcanic activity and that had never been connected with landmasses, allowing the establishment of biotas that evidence community characteristics such as disharmony, higher rates of endemism per area and, sometimes, relictualism (Gillespie, 2007). Moreover, oceanic islands have fewer interactions between species due to the lower diversity rates and disharmonic communities, this is, communities lacking entire groups (Vitousek, 1988). Therefore, when one species disappears it has serious consequences for the ecosystem (Gillespie, 2007).

The Macaronesian region is composed by five oceanic archipelagos located north of the Atlantic Ocean: Madeira, Azores, Selvagens, Canaries and Cabo Verde. The climatic gradient in Macaronesia goes from the oceanic tropical monsoon-drift climate of the Cabo Verde Islands to the Mediterranean climates of Madeira, Selvagens and the Canaries Island and finishing with the cool-oceanic climate of the Azores (Fernández-Palacios & Dias, 2001). These archipelagos are all included in a biodiversity hotspot, the Mediterranean basin; thus are biodiversity rich and hold many threatened species (CEPF, 2016). In this hotspot, there are approximately 30,000 plant species, half of which are endemic, and a high diversity of marine and terrestrial fauna (CEPF, 2016). The ecology of species in Macaronesia has been widely explored by renowned scientists,

including Darwin and Wallace, but Cabo Verde was the least explored archipelago. In addition, temperatures in Cabo Verde are raising even more than in any other Macaronesian archipelago (Cropper & Hanna, 2014).

The Cabo Verde Archipelago is located about 500 km off the West African coast (**Fig. 1.1**). The archipelago forms a horseshoe-shape and it is constituted by ten islands and several islets (Mitchell-Thomé, 1976). The islands are dated from 26 to circa 2 million years old (My), with the islands closer to the mainland being the oldest, while islands far from the mainland are the most recent (Ancochea et al., 2015; Mitchell-Thomé, 1972; Mitchell et al., 1983; Plesner et al., 2003). The islands of Cabo Verde can be divided into three main groups according with their age, characteristics and locations (**Fig. 1.1**) (Holm et al., 2008). The northern group is constituted by São Nicolau, São Vicente, Santo Antão and the Desertas Islands of Santa Luzia, Branco and Raso. The eastern group is composed by Boavista and Sal islands. The southern group includes Maio, Santiago, Fogo and Brava islands and Rombos Islets. The areas and elevations of the islands vary markedly: Santiago is the largest (around 1000 km^2), Santa Luzia the smallest (<34 km^2) and Fogo the highest (about 2829 m) of the archipelago (Mitchell-Thomé, 1972).
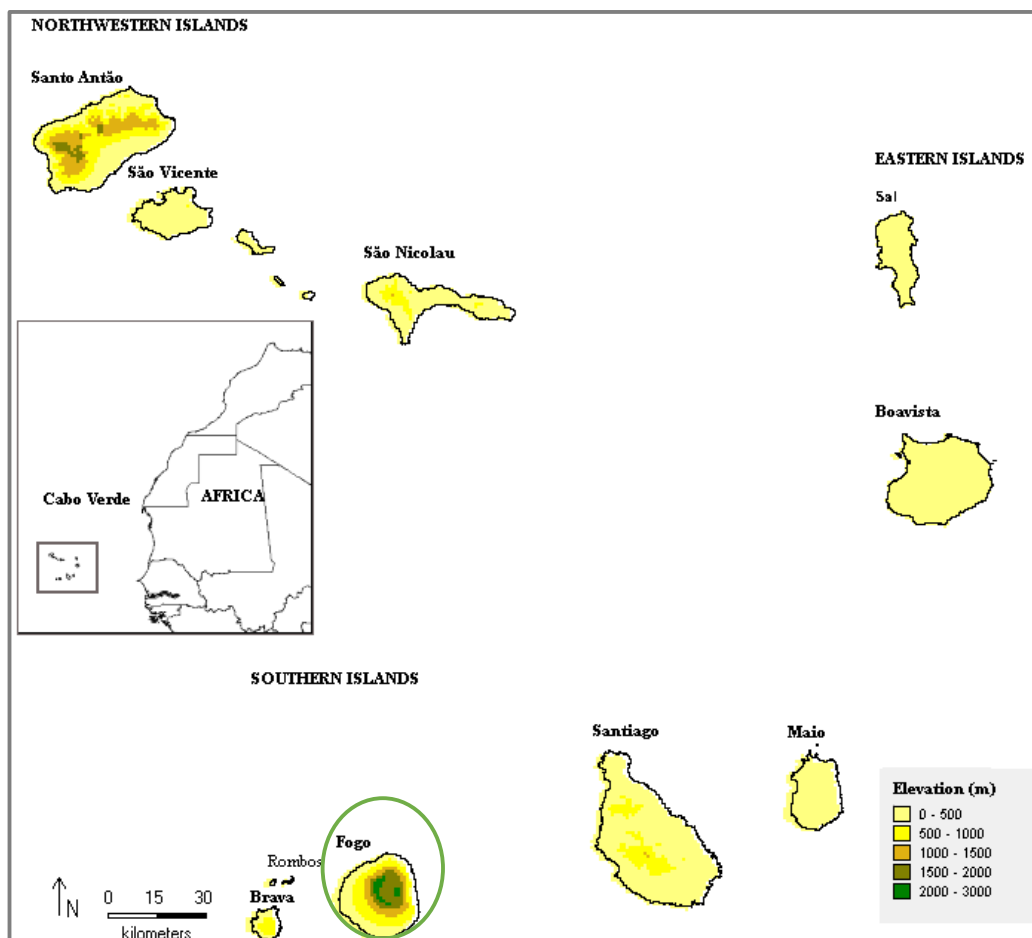
Figure 1.1. Location of the Cabo Verde Archipelago in Africa and of its islands in the island groups. Colours represent elevation intervals. The study area is marked with a circle.

Cabo Verde presents 1768 indigenous species of arthropods, of which 473 are endemic (Triantis et al., 2010). In addition, the vascular plant flora of Cabo Verde includes 736 taxa with 92 endemic species of which 72 are threatened (Romeiras et al., 2016). Cabo Verde holds six endemic bird species and 16 endemic bird subspecies (Duarte & Romeiras, 2009). There are 31 indigenous reptile species, and interestingly, all of them are endemic and about half of them are threatened (Vasconcelos et al., 2013). This archipelago has the largest number of species of reptiles in Macaronesia (Vasconcelos et al., 2013) and is therefore considered a good model for herpetological studies. In Cabo Verde, mammals are poorly represented, having no endemic mammal species so far (Borloti et al., 2020).

Fogo Island, the study area, belongs to the southern group (**Fig. 1.1**) and is around 3.2 to 5.1 My (Madeira et al., 2008). Fogo harbours the most active terrestrial volcano in the archipelago (last eruption in 2015) which is also its highest point (Pico do Fogo). The presence of this volcano allows the formation of a humid region located in the northeast, and a more arid regions are in the southwest, because Pico do Fogo blocks the trade winds preventing them to go southwest (Olehowski et al., 2008). Land use and land cover on Fogo vary from mixed forest and shrub-vegetation areas to coastal savannah and extensive graze farming (Olehowski et al., 2008). Fogo Island has an area of 476 km^2 and is the fourth largest island of the archipelago (Turner, 2014). The climate of Fogo Island ranges from tropical to semi-arid (Olehowski et al., 2008), with an average temperature of 25 °C and an average precipitation of 230.4 mm/ year (Stackhouse et al., 2015). Due to the northeast trade winds, precipitation varies in the different parts of the island. Most of the precipitation is caused by mist (Hazevoet, 1995; Jefferson et al., 2014), which is formed in high altitudes areas by condensation of clouds and produced by trade winds. Mist may represent 1.5 to 3 times the normal amount of rainfall in other Macaronesian islands (Figueira et al., 2013).

Fogo Island presents 42 endemic plants from Cabo Verde, six exclusive from this island (Romeiras et al., 2016), four breeding endemic birds (Barone & Hering, 2010) and six reptiles species endemic of Cabo Verde (Vasconcelos & Dinis, 2017), and four endemic of this island (Vasconcelos et al., 2013). Fogo Natural Park was one of the firsts protected area to be established in Cabo Verde (Anonymous 2003).

1.3 Reptiles: unpopular but important for conservation

Reptiles are a paraphyletic group of terrestrial vertebrates with high diversity, about 11,050 species (Uetz et al., 2020). They are distributed worldwide and occur in all continents, except Antarctica (Böhm et al., 2013). Reptiles are ectotherms with low metabolic rates (Huey, 1982). Moreover, this

group are great island colonizers just surpassed by birds and plants (Case & Cody, 1983), and overtaking mammals and amphibians, as they have low metabolic rates and high desiccation resistance (Ali & Meiri, 2019). As reptiles are usually quite abundant on islands, they are a good model for ecological studies (Case & Cody, 1983). Herpetofauna also presents high endemism rates on islands (Böhm et al., 2013), usually higher than other vertebrates (Kier et al., 2009). The major threat for their decline is mainly due to introduced species, anthropogenic factors, habitat fragmentation and CC (Ficetola & Padoa-Schioppa, 2009; Smith et al., 2012; Wake, 2007). As ectotherms, they are sensitive to CC (Böhm et al., 2016), and so their life history traits are influenced by environmental temperature variation (Diele-Viegas & Rocha, 2018). For this reason, reptiles are excellent models to evaluate potential effects of CC on terrestrial ectotherms (Chamaillé-Jammes et al., 2006). In addition, they are often in the top of the ecological networks and are very important on island ecosystems. They often act as seed dispersers, pollinators (Godínez-Álvarez, 2004), bioindicators (Read, 1998) and are important in the food chain as intermediaries or even as top predators (de Miranda, 2017), and for these reasons, by protecting reptiles, we probably protect a large group of interactions. However, reptiles are poorly studied and therefore it is more difficult to conserve them. Due to lack of data, it is unknown how many reptile species are threatened in the world (Bland & Böhm, 2016; IUCN, 2020).

In Cabo Verde, two endemic reptile species, *Chioninia coctei* (Duméril et al., 1839) and *Geochelone atlantica* (López-Jurado et al., 1998), already went extinct, and CC was one of the main drivers for their extinction (Vasconcelos et al., 2015). In Cabo Verde, there are three genera of reptiles i.e. *Tarentola*, *Hemidactylus* and *Chioninia* (Vasconcelos et al., 2013). The first one, *Tarentola* Gray, 1825, is a genus of the family Phyllodactylidae, commonly called wall geckos. *Hemidactylus* Gray, 1845, is one of the most species-rich genera of the family Gekkonidae. The *Chioninia* genus Gray, 1845 belongs to the Scincidae family, generally named as skinks, one of the most diverse families of squamates (Pianka et al., 2003), with about 1275 species (Uetz et al., 2020). *Chioninia* are diurnal and for a long time, belonged to the genus *Mabuya* Fitzinger, 1826 that was a very large pantropical genus of lizards including more than 110 species in tropical areas of Africa, Asia, and South and Central America (Greer & Nussbaum, 2000). After some phylogenetic analyses, this group was separated into four genera, namely *Mabuya*, from South and Central America, *Eutropis* Fitzinger, 1843 from Asia, *Trachylepis* Fitzinger, 1843 from Madagascar and Africa, and *Chioninia* exclusive from Cabo Verde (Carranza & Arnold, 2003; Mausfeld et al., 2002). There are seven *Chioninia* species and 12 taxa within this genus (Vasconcelos et al., 2013) distributed across the Cabo Verde Archipelago. The ancestor of *Chioninia* probably colonized Cabo Verde through transmarine migration by natural rafts of vegetation, profiting from the northeast trade winds and currents (Carranza et al., 2001) about 26 to 33 My (Karin et al., 2016; Metallinou et al., 2016; Pereira & Schrago, 2017). About 33% of *Chioninia* taxa are threatened by natural disasters, intrinsic factors of the species, CC and introduced species (Vasconcelos et al., 2013).

One of this endemic threatened species is *Chioninia vaillantii* (Boulenger, 1885). The Vaillant's skink or 'lagarto chinel' in Cabo Verdean creole (**Fig. 1.2**), is classified as Endangered by the

International Union for Conservation of Nature (IUCN) red list due to the reduced extent of occurrence and area of occupancy in which is present and continue declining in the quality of its habitat (Vasconcelos, 2013b). Its major threats are habitat fragmentation and disturbance, persecution, because this species competes with farmers for fruits, natural disasters (e.g. volcanic activities on Fogo Island) and introduced species (Vasconcelos, 2013b). Another threat is related to intrinsic factors, because this species is viviparous (Metallinou et al., 2016), and so has relatively low reproductive output (Vasconcelos, 2013b). This species is endemic and restricted to northern side of Fogo Island, the inland of Santiago Island and Cima Islet, in Rombos (Vasconcelos et al., 2013). It presents two subspecies: *Chioninia vaillantii vaillantii* (Boulenger, 1885) and *Chioninia vaillantii xanthotis* (Miralles et al., 2011). This latter subspecies occurs on Fogo Island and Cima Islet and differs from *C. vaillantii vaillantii* by presenting a yellow ear, a faded greyish colouration of the chin and a brownish colouration of the snout, and a higher number of rows in the transversal scales along the body than *C. vaillantii vaillantii* (Miralles et al., 2011). The latter taxa occurs only on Santiago Island and presents ear-openings grey or whitish, a bright orange colouration of the chin and snout and a lower number of transversal scale rows along the body (Miralles et al., 2011). *Chioninia vaillantii* is only found in humid areas, mostly in agricultural land with vegetation-covered stonewalls. This species is protected under Cabo Verdean national legislation (Schleich, 1996). Despite that, IUCN claims that research is required to clarify the population status, natural history and impacts of threats of this species, and education to raise awareness about its conservation needs (Vasconcelos, 2013b). The Cabo Verde population, like the majority of the human population, fears reptiles (Vasconcelos et al., 2014), making conservation measures more difficult to implement.

The Delalande's skink, *C. delalandii* is another species from Fogo Island (**Fig. 1.2**). Is widely spread across the island (Vasconcelos et al., 2013) and is shorter than *C. vaillantii* (52 mm against 92 mm; Miralles et al. 2011). *Chioninia delalandii* is listed as Least Concern by the IUCN Red List (Vasconcelos, 2013a). This species occurs on Santiago, Fogo and Brava Islands and on Rombos Islets.
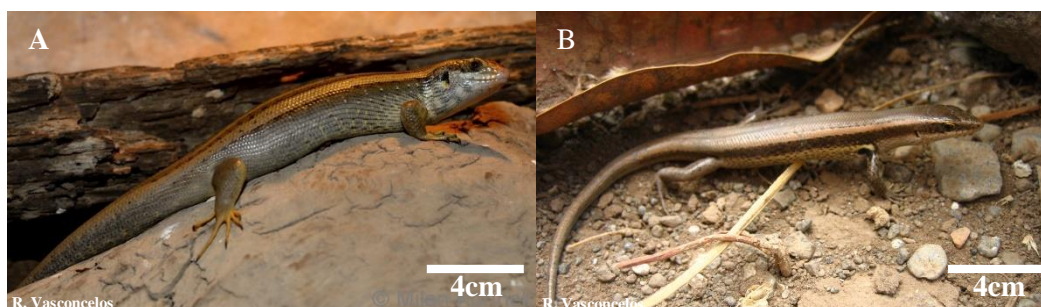
Figure 1.2. Endemic species studied in this thesis. **A)** Vaillant's skink, *Chioninia vaillantii* and **B)** Delalande's skink *Chioninia delalandii*.

1.4 GENERAL OBJECTIVES

The objective of this master thesis is to contribute to understanding the ecology of *C. vaillantii* and to promote environmental education in the community in order to protect it. More concretely the objectives are to: 1) understand the thermal preferences of *C. vaillantii*; 2) perceive the influence of water availability in *C. vaillantii* thermoregulation; 3) understand the physiological response of *C. vaillantii* in low humidity conditions; 4) and how viviparous *C. vaillantii* females physiologically responds to shifts in temperature and humidity in comparison with *C. delalandii*; 5) evaluate the impact of a movie production activity in perceptions, feelings and actions of students towards reptiles in general and *C. vaillantii* in particular.

With these findings, I hope to give some scientific support to the conservation plan of *C. vaillantii* by unveiling its hydric and thermal preferences and by promoting the awareness in the local community about its conservation needs.

1.5 GENERAL REFERENCES

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2. MANUSCRIPT I

Hot is worst if dry: an ecophysiological message from Cabo Verde lizards

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Abstract

Climate change (CC) scenarios forecast intense environmental shifts in the Mediterranean Basin biodiversity hotspot, and sedentary ectotherms are expected be the most affected organisms. We expected to provide clues on how species inhabiting milder climates will respond to CC analysing the physiological responses of reptiles inhabiting the most arid and warmest areas in this region. Cabo Verde Archipelago presents high numbers of endemics, some threatened by CC. On Fogo Island, two endemic viviparous skinks have contrasting sizes and distributions. While *Chioninia vaillantii* is larger and restricted to cooler/ humid areas in the northeast, *Chioninia delalandii* is smaller and distributed across the island, even in hotter/ more arid areas. This suggests that the first is more restricted in its thermal/ hydric ecophysiology than the second, explaining its distribution. Additionally, pregnant females are expected to be more sensitive to CC. We experimentally tested both hypotheses by measuring evaporative water loss (EWL) rates, and determining preferred body temperatures (Tp) and space use of 10 individuals of both species, with/ without water available. The species differed in EWL due to surface/ volume ratio differences. *Chioninia delalandii* kept higher Tp and was more frequently found in the hot part of the terrarium than *C. vaillantii*. As expected, lack of water affected Tp, and all pregnant females selected lower Tp than conspecific males and non-pregnant females. This evidence confirms recent findings, suggesting that water ecology modulates thermoregulation in ectotherms, and that aridification will intensify CC effects. Overall, Cabo Verde lizards may be useful models of the Mediterranean Basin ectotherms for Conservation Biology.

Keywords: Climate change; *Chioninia*; Fogo Island; thermal and hydric ecology; viviparity; Scincidae

2.1 INTRODUCTION

Climate change (CC) is one of the main threats to biodiversity because it is inducing major shifts in the abiotic conditions of organisms at a fast rate. Factors such as metabolic rate (Dillon et al., 2010), morphology (Sheridan & Bickford, 2011), behaviour (Biro et al., 2009), life cycle (Bestion et al., 2015), and distribution (Chen et al., 2011; Parmesan & Yohe, 2003) are being affected by CC and consequently altering ecosystem structure and interactions (Walther, 2010). Not only the environment is becoming warmer (Giorgi & Lionello, 2008), but also drier (Dai, 2013). However, not all species respond in the same way to these changes. Those that have limited dispersal and homeostasis are the most exposed, such as the case of reptiles (Wake, 2007). Cold-adapted species such as reptiles have been documented to suffer declines because global warming is approaching their critical thermal maxima (Sinervo et al., 2010). However, much less is known on the effects of CC in the precipitation regimes, which is many cases involves aridification and longer drought periods.

The Mediterranean basin biodiversity hotspot is one of the 36 biodiversity hotspots of the planet (CEPF, 2016; Myers et al., 2000). Due to its complex geography and evolutionary history some of its areas harbour high rates of endemism and unique communities (Médail & Quézel, 1999). Most of them are insular areas. The Mediterranean basin hotspot contains almost 5000 islands and islets. Island systems are disproportionately represented in relation to continental systems in biodiversity hotspots (Cuttelod et al., 2009) because of their unbalanced communities and high vulnerability of endemics to stochastic events and invasions by continental species, either as competitors, predators or parasites (Kier et al., 2009; Whittaker & Fernández-Palacios, 2007; Whittaker et al., 2017). Human intervention is increasing the frequency of disturbances, such as CC, and effects like droughts and heatwaves are becoming more frequent, inducing increases in extinction rates (Dai, 2013; Diffenbaugh et al., 2007; Fischer & Schär, 2010). Endemics of insular systems often go extinct due to CC because of their limited possibilities to shift their ranges to higher altitudes (Sinervo et al., 2010).

Reptiles also present high endemism rate on islands (Böhm et al., 2013) and the general forecast is for their decline mainly due to introduced species, anthropogenic factors, fragmentation and CC (Ficetola & Padoa-Schioppa, 2009; Smith et al., 2012; Wake, 2007). As ectotherms, reptiles depend on the physical environment to maintain the body temperature (Huey, 1982). They are able to maintain their optimal body temperature by adopting behavioural postures and selecting favourable thermal microhabitats as a response to the environment (Huey & Slatkin, 1976; Sears & Angilletta, 2015). For many reptiles that live in tropical or desert areas, the challenge for thermoregulation is how they can keep cold rather than warm (Kearney et al., 2009). However, the basic ecology of reptiles in general, and lizards in particular, is frequently understudied (Pianka et al., 2003). One of the problems in the current literature is that, most of the works, only consider temperature as a thermoregulation factor. However, humidity can also be important (Daltry et al., 1998) and some studies show that water availability is important in thermoregulation of lizards (Lorenzon et al.,

1999; Sannolo & Carretero, 2019). Remarkably, thermoregulation and water balance may trade-off in reptiles (Mautz, 1982). Recent research on temperate lizards confirms that water loss may constrain thermoregulation, activity, habitat use and distribution when access to water is restricted (Belasen et al., 2017; Dupoué et al., 2020b; Rozen–Rechels et al., 2019; Ryan et al., 2016; Sannolo & Carretero, 2019). Moreover, under the same conditions, large reptiles are expected to display lower water loss rates than small ones due to lower size-volume relationship (Schmidt-Nielsen, 1997).

Another relevant aspect is the reproductive mode of the species. Viviparity in squamates evolved multiple times from oviparity (Blackburn, 1982; Pyron & Burbrink, 2014), and it is thought to be the result of a progressive increase of the developmental time of embryos inside the oviduct (Tinkle & Gibbons, 1977). Three adaptive hypotheses have been proposed on the evolutionary pressures promoting the transitions for oviparity to viviparity: the cold-climate hypothesis (Shine, 1985, 2002b), the climatic predictability hypothesis (Shine, 1995, 2002a), and the maternal manipulation hypothesis (Shine, 1995; Webb et al., 2006). The first purposes that in cold climates females that could retain the eggs longer had more reproductive success due to higher developmental viability and lower energy consumption (Ma et al., 2018). The second proposes that females could prevent embryos to be exposed to extreme temperatures, as those found in nests, by postponing oviposition until conditions are optimal for egg-laying (Tinkle & Gibbons, 1977). More recently, the second hypothesis has been expanded to non-thermal factors, namely, that lizard mothers inhabiting seasonally dry environments would buffer hydric variations of embryos (Bonnet et al., 2017). Lastly, the maternal manipulation hypothesis suggests that viviparity evolved because it improved offspring fitness by modifying developmentally sensitive phenotypic traits (Shine, 1995). While only a comparative analysis across the phylogeny will allow determining the contribution of thermal and hydric environment to the origin and diversification of viviparity among squamates, it is a fact that multiple viviparous species inhabit warm environments (Ma et al., 2018), among them the *Chioninia* skinks from Cabo Verde (Metallinou et al., 2016). *Chioninia* species evolved *in situ* (Miralles et al., 2010) and constitute a good model to test the influence of environmental pressure on distribution range via thermal and hydric ecophysiology, since they are easy to manipulate in the lab, locally abundant, and sedentary.

Cabo Verde Islands are part of the Mediterranean basin biodiversity hotspot and hold the highest number of reptile taxa of Atlantic archipelagos in that area. Here, we test the general ecophysiological hypotheses that the distinct distribution patterns of two *Chioninia* species in Fogo Island are associated with differences in their hydric and thermal preferences and that pregnancy affects those preferences. We predict that: (1) lizards will be more constrained for selecting body temperatures across a heterogeneous thermal environment when water is not available than when water is available; (2) relative water loss will increase with decreasing lizard size because of the higher surface/ volume ratios; (3) accordingly, the smallest species will display higher water loss when restricted to low humidity conditions; and (4) pregnant females will either shift their thermal

preferences and/or minimise water loss when compared to conspecifics in order to prevent embryo dehydration.

Beyond the biogeographic interpretations, the outcomes of this work are also expected to shed light on the vulnerability of lizard species to environmental disturbance in a context of global warming and aridification in the Sahara-Sahel region and the Mediterranean basin biodiversity hotspot.

2.2 METHODS

2.2.1 Study area

Fogo is a volcanic island originated between 3.2 to 5.1 million years ago, Ma (Madeira et al., 2008). It is the highest and the fourth largest island in the Cabo Verde Archipelago **(Fig. 2.1)**, with elevations of 2829 m above sea-level and an area of 476 km^2 (Medina & Santana, 2017). It belongs to the southern island group of the archipelago and is sites around 800 km off the African coast. The climate ranges from tropical to semi-arid, with an average temperature of 25 °C (Stackhouse et al., 2015). It presents an active oceanic volcano, Pico do Fogo (last eruption in 2015) that prevents the northeast winds to go southwest promoting differences in precipitation and temperature regimes (Olehowski et al., 2008). In this way, that the north-eastern part of the island is colder and more humid than the south-western part (Olehowski et al., 2008). Therefore, Fogo is a good study area for testing our ecophysiological hypotheses because it is very heterogeneous for such a small island. Moreover, Fogo Island presents three endemic viviparous skinks (Miralles et al., 2010): *Chioninia vaillantii xanthotis* Miralles et al., 2010, *Chioninia delalandii* (Duméril et al., 1839) and *Chioninia spinalis spinalis* (Boulenger, 1906). This is an interesting study area as these species, being viviparous, are expected to be more sensitive to global warming (Sinervo et al., 2010).

2.2.2 Study species

This study focused on *C. v. xanthotis* and *C. delalandii*, as *Chioninia s. spinalis* is found in different locations than the other two species and belongs to a different phylogenetic clade (Miralles et al., 2010; Vasconcelos, 2013). Genetic analysis supports that these two species split into two different taxa about 6.9–5.9 Ma (Miralles et al., 2010). The first is mostly restricted to the northwestern areas (Vasconcelos et al., 2013), probably due to higher precipitation and/ or lower temperatures. The second, is widely spread across all the island (Vasconcelos et al., 2013). *Chioninia v. xanthotis* (87.5–105 mm) is larger than *C. delalandii* (52–92 mm), but is found mainly on remains of agricultural stonewalls and other rock walls with vegetation cover in sub-humid and humid areas. The sister taxa *C. delalandii* is often seen on rocks on several habitats, from sub-humid to arid areas (Miralles et al., 2010; Vasconcelos et al., 2013).
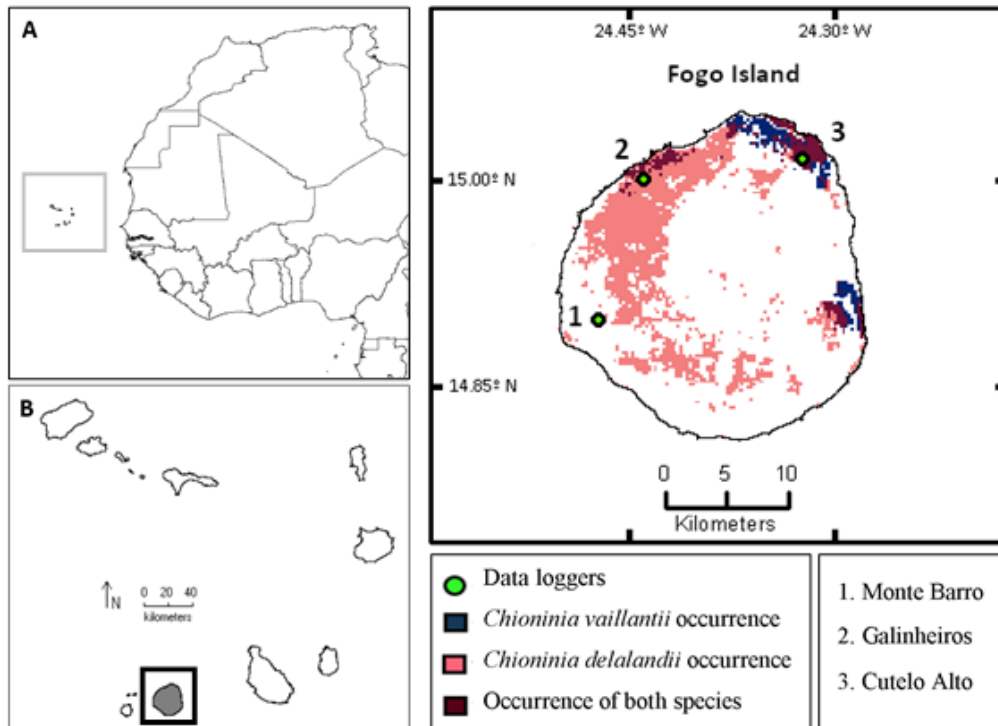
Figure 2.1. Map of the Cabo Verde Islands showing the archipelago (**A**) and Fogo island location (**B**) and the study areas (**C**). The probability of occurrence of *Chioninia vaillanti* (in blue) and *Chioninia delalandii* (in rose) on Fogo are depicted (calculated using Maximum Entropy environmental niche-based models, adapted from Vasconcelos et al. 2012). Purple represents the overlap of the predicted ocurrence areas for both species.

2.2.3 Environmental characterization

To register the temperature and humidity available for the reptile species, we placed nine data loggers (iButton, DS1923) in three representative sites: Monte Barro (14.899, -24.473), Galinheiros (15.001, -24.440) and Cutelo Alto (15.016, -24.324). The first one is within the area of low probability of occurrence of *C. vaillantii* (Vasconcelos et al. 2012). The other two localities belong to the area where the two species have higher probability of occurrence and registered observations (**Fig. 2.1**). Because *C. vaillantii* is often seen on stone walls and *C. delalandii* seen on big rocks (Vasconcelos et al., 2013), we placed three data loggers in three distinct microhabitats protected from sun exposure: vegetation, big rocks and stonewalls.

2.2.4 Sampling

We randomly captured 10 individuals of each species in Cutelo Alto using pitfalls during the day of May 15 2019. We have marked them in the venter using individual codes with a permanent marker. We shot 10 photos of each animal: one on the dorsal and one on the ventral side, one of the dorsal part of the head, one on the underside of the snout, one of each side of the head, and one

of each limb. This would allow us to identify each animal in case the marks would be lost. We sexed each animal by examining the cloacal region and everting the hemipenises, as well as, palpating females with prominent bellies to determine the presence of embryos. As a result, we identified four males, three non-pregnant females, and three pregnant females of *C. vaillantii*, and five males, two non-pregnant females, and three pregnant females of *C. delalandii* (**Table S2.1** in Supplementary Material). The lizards were transported in individual bags to the lab in São Filipe (14.53, -24.29) minimising stress.

We measured the snout-vent length (SVL) of lizards with a calliper to the nearest 0.01 mm and their body mass (BM) with a portable digital scale (My Weight Flipscale F3; precision 0.01 g; maximum weight 100 g) before the experiments (**Table S2.1**).

2.2.5 Preferred body temperatures and space use

We set up 10 terraria with PVC plates and tape (100x40x30 cm). The temperature of the room was established at 21ºC and all the windows were covered to prevent natural light to enter the room. We lit up the room with artificial light at 7:00 am until 8:00 pm because both species are active by day and inactive by night. We placed an infrared lamp (150W) above one end of the terraria to create a thermal gradient of temperatures from 24 to 73ºC, approximately. We placed a small plastic box with water in the centre of the terraria (Sannolo & Carretero, 2019). When lizards where not in the experiments, they were placed in containers with water *ad libidum*. During the first 24h we let lizards to randomly choose temperature gradient for acclimation, allowing them to explore the terrarium. Lizards were left undisturbed with no food but water *ad libitum* to ensure that they were fully hydrated before the start of the experiment. Infrared lamps were lit on at 7:00 am and turned off at 7:00 pm. On the second day, we randomly covered the water boxes of half of the terraria to prevent lizards from drinking. In the third day, we repeated the trial covered the water boxes of other half of terraria and uncovering those of the first half to have access to water.

The position of the lizard inside the gradient was classified into three zones, of approximately 33x30 cm each, according to the distance to the heat source: cold, middle or hot. The plastic box with water was in the middle zone (**Fig. 2.2A**).

Every hour, from 8:00 am to 7:00 pm, we measured the body temperatures with a thermal picture using a FLIR Cat S61 thermal camera. We followed the method described by Barroso et al. (2016) to assess the preferred body temperature (Tp) of the species since it provides a good correlation with the internal temperature. We extract Tp from each infrared picture using the Area function in FLIR Tools. We selected one spot in the head (Th), one spot in the trunk (Ta) and one spot between the legs of each lizard (Tl). We also recorded the positions of each lizard within a section inside the gradient whenever at least half of its body was in that section. When an animal was exactly in the middle of two sections, we recorded it as 'no data'.
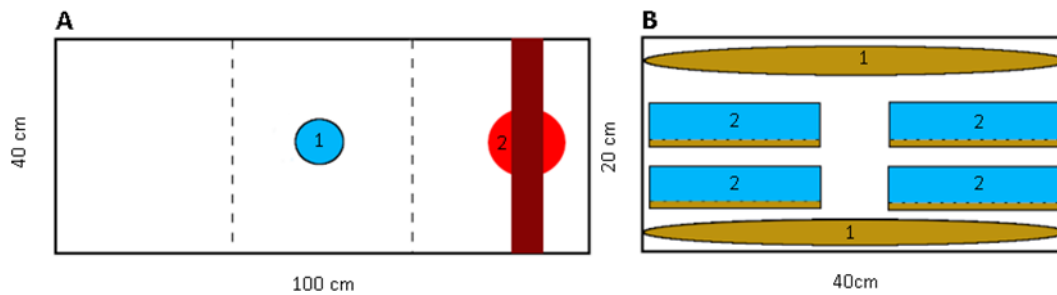
Figure 2.2. Layouts of the thermoregulation and hydric experiments. **A)** Layout of the terraria used in the preferred body temperature and spatial use of the gradient experiment: 1. plastic box with water; 2. 150W infrared lamp; the dashed lines separate the cold, middle and hot zones. **B)** Layout of the hermetic and opaque plastic box where it was placed: 1. net bags with 100g of silica; 2. plastic containers for the lizards with 5 g of silica (not in direct contact) for the experiment on loss of evaporative water.

2.2.7 Evaporative water loss

At the end of the second and third day, at 19:00h, after taking the last thermal picture, we weighted the animals to calculate water loss in the gradient experiment. We deliberately avoid re-weighting the animals before the thermoregulation experiments to avoid biases in their behaviour. At the end of third day, we allowed the lizards to rehydrate but not to eat.

On the fourth day we ran the water loss experiment (**Fig. 2B**). First, we weighted the 10 individuals and then place them in individual plastic containers (30 cm x 8 cm x 8 cm), where they were separated from 5 g of silica gel by a plastic board with holes. The containers had holes on top to allow ventilation. We placed containers in groups of five inside a hermetic and opaque plastic box (40 cm x 20 cm x 25 cm). Inside each plastic box, we placed more 100 g of silica gel in net bags to avoid direct contact with the lizards. In this way, we lowered humidity from 60–50% to 25–30% and stabilized, measured with a CAT S61 (VOC sensor by Sensirion, precision 3%). This experiment ran for eight hours during daytime, at the end of which, lizard containers were removed and weighted again using the precision balance to calculate evaporative water losses (WL in grams, WL% and in percentage of the BM before the experiment).

2.2.8 Statistical analysis

We used Generalized Linear Model (GLZ) in Statistica (Dell, 2016) to test for differences in humidity and temperature monitored with data loggers among sampling sites, microhabitat, day and time.

Differences in Tp, Th, Ta and Tl between species (*C. vaillanti* or *C. delalandii*), tests (water available or unavailable), terrarium zones (cold, middle or hot) and classes (male, non-pregnant female or pregnant female; M, F and Fp, respectively) were tested with Linear mixed-effect models using lmer R-package from the lmer library. We used individuals as random factor.

To know if there were differences in spatial use between species, test type and classes we used Generalized Linear Mixed-Model (GLMM) using glmer R-package from the lmer4 library run in R version 3.6.1 (Core Team, 2013). We used zone as dependent variable and test, species and pregnancy (Preg; pregnant or non-pregnant individual) or class as independent variables, and individual code and hour as random factors (see Suplementary Table S2.4 for further details).

The differences in BM between the beginning of the first day and the end of the third day was used to calculate the variation of body mass in water (ΔW, in grams, $\Delta W\%$ in percentage of the initial BM, BMi, and $\Delta W/SVL$, balanced per SVL). We tested differences in ΔW, $\Delta W\%$ and $\Delta W/SVL$ using Linear mixed-model in Statistica. As factors we used species, test type and class. We used individual code as random factor and SVL and BMi as covariates; both for ΔW, SVL for the $\Delta W\%$ and BMi for $\Delta W/SVL$ tests. Comparisons of the water loss experiment were evaluated with GLM, first without covariates and then introducing SVL and BM as covariates.

Following Zuur et al. (2009), we choose models for available temperature and humidity, preferred body temperature, space use, and body mass variation with the lowest AIC score, lower complexity and the most explanatory significant results (see Suplementary Table S2.1 to S2.5 for further details).. According to Burnham and Anderson (2002) models with $\Delta AIC < 2$ were considered to provide substantial information. The significance level was set at $p = 0.05$ in all cases.

2.3 RESULTS

2.3.1 Environmental characterization

Measurements of data-loggers revealed significant variation in the environmental regimes of the three representative sites and microhabitats (**Fig. 2.3; Table S2.2**). Thus, there were significant differences in humidity for all factors (site, microhabitat, hour and day) ($\chi LR = 2320.66$, d.f.$= 37$, $p < 0.01$; Table S2). For the temperature, the same factors were important ($\chi LR = 489.97$, d.f.$= 37$, $p < 0.01$; Table S2). Remarkably, humidity was generally lower in Monte Barro, outside of the predicted area of occurrence of *C. vaillantii* populations, while Cutelo Alto presented lower temperature than Monte Barro and Galinheiros. Among the three microhabitats, big rocks and vegetation attained the highest temperatures and walls and vegetation retained more humidity (**Fig. 2.3**).
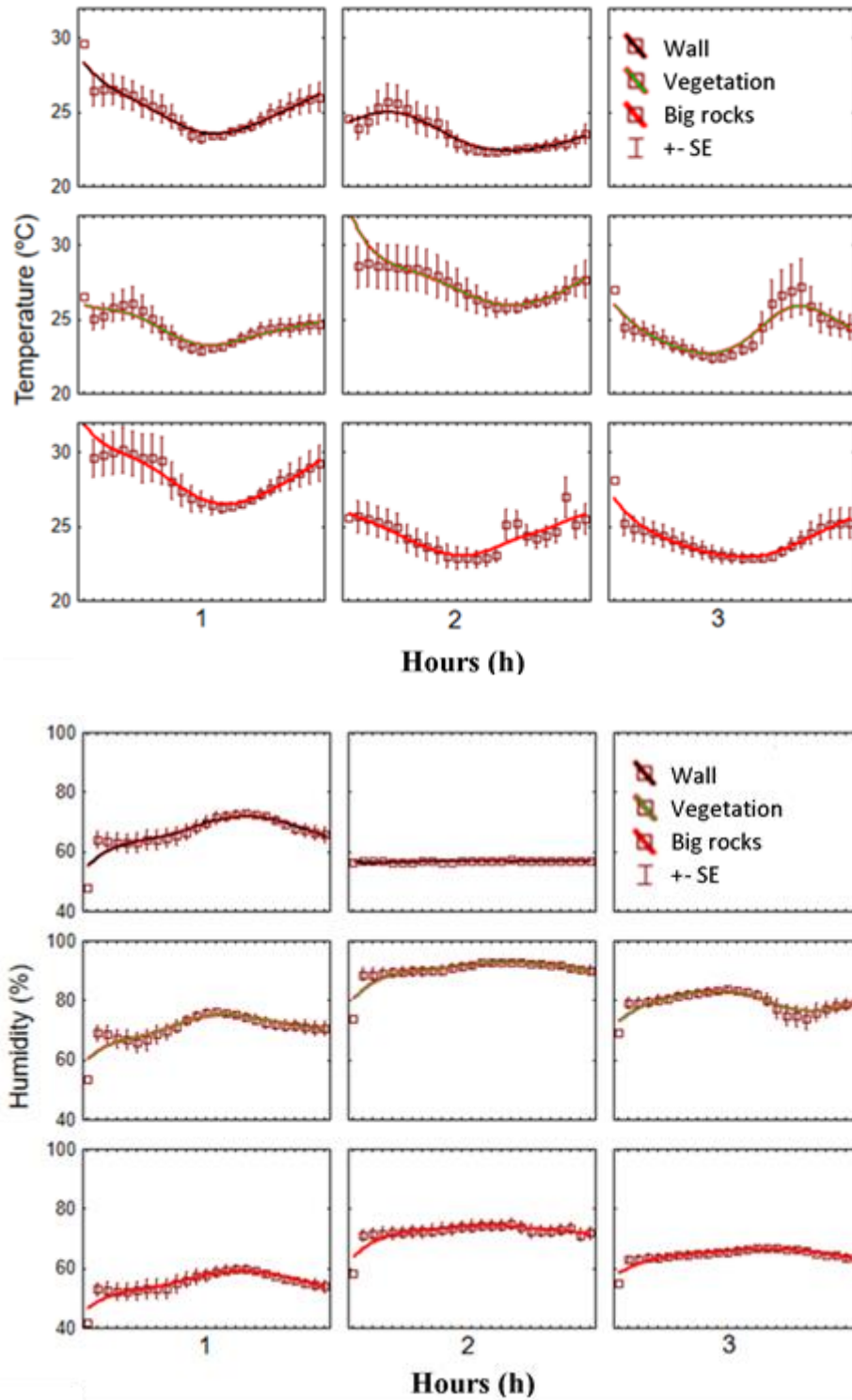
Figure 2.3. Data-loggers measures. The values of the mean humidity and temperature and standard error (whiskers) of each hour for the three microhabitats (black, wall; green, vegetation; red, big rock) in the three studied sites (1, Monte Barro; 2, Galinheiros; 3, Cutelo Alto) are given along 22 days. One data logger was lost in microhabitat 3.

2.3.2 Morphological differences

There were differences in SVL ($F_{(20,1)}$= 218.89, $p<$ 0.01) and initial BM ($F_{(20,1)}$= 96.15, $p<$ 0.01) between species. *Chioninia vaillantii* presented higher BM than *C. delalandii* even when SVL is used as covariable ($F_{(20,1)}$= 10.08, $p<$ 0.01). Furthermore, pregnant females present higher BM than males and non-pregnant females when SVL was used as covariable ($F_{(20,2)}$= 184.08, $p<$ 0.01).

2.3.3 Preferred temperatures and space use

Inside the gradient, *C. vaillantii* selected significantly lower temperatures than *C. delalandii* (31.52ºC versus 33.41ºC on average, respectively; **Fig. 2.4** and **Table S2.1** and **S2.3**; t-value $_{(1440, 40.81)}$= 5.729; $p<$ 0.001). Selected temperatures of *C. vaillantii* were significant higher, on average of +1.43ºC, when water was restricted comparatively to when water was available (t-value $_{(720, 710.00)}$= -5.087; $p<$ 0.001; **Fig. 2.4** and **Table S2.3**).
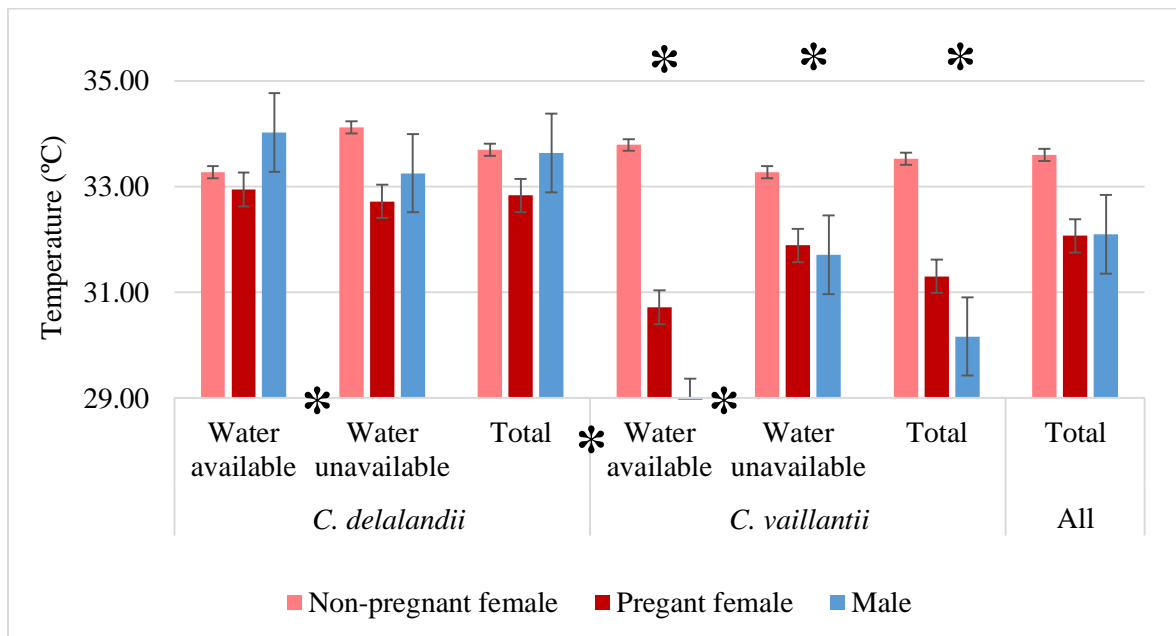
Figure 2.4. Selected temperatures by each class (non-pregnant females, pregnant females and males) and overall *C. delalandii* (N=1440) and *C. vaillantii* (N=1440) and average values for both species per class. Significant differences between species, tests and among classes represented by asterisks. Three body temperatures of 10 individuals of each species were recorded each hour along 12h per test. Error bars represent Standart Error.

When considering both species, pregnant females attained lower temperatures than non-pregnant females and males (t-value $_{(1440, 37.07)}$= 3.166; $p=$ 0.0030; **Fig. 2.4** and **Table S2.3**). Males attained

lower temperatures than pregnant-females and non-pregnant females in *C. vaillantii* (M: 30.17ºC, Fp: 31.30ºC and F: 33.53ºC; t-value $_{(720,18.08)}$= -2.931; *p*= 0.009). Pregnant-females of *C. delalandii* attained significantly higher temperatures than of *C. vaillantii* (32.83ºC vs 31.30ºC; t-value $_{(1440, 39.68)}$= -4.755; *p*< 0.001; **Table S2.1**). Also, in *C. vaillantii*, when water was available, males and pregnant-females attained lower temperatures than when it was unavailable, contrary to non-pregnant females (M: 28.62ºC vs 31.71ºC; Fp: 30.72ºC vs 31.89ºC; F: 33.79ºC vs 33.27ºC, respectively; **Table S2.1**; t-value $_{(720, 713.53)}$= -4.657; *p* < 0.001).

In *C. delalandii* body temperatures were significantly lower, on average -0.28º, when water was restricted than when water was available (t-value $_{(720, 717.61)}$= -2.555; *p*= 0.011). Despite of no significant differences of Tp among classes (**Fig. 2.4**; t-value $_{(720, 233.27)}$= 1.572; *p*= 0.117), there was a significant interaction between zone and class in *C. delalandii* (t-value $_{(720, 719.99)}$= -2.151; *p*= 0.032). Pregnant-females attained lower temperatures than non-pregnant females and males when in cold and hot zones (Cold: Fp= 29.87ºC, F= 30.44ºC and M= 31.80ºC, respectively; Hot: Fp=33.66ºC, F= 34.42ºC and M= 34.15ºC).

Considering species regardless of the class, there were also differences in the use of space according to the test (when water was available or unavailable; z-value $_{(1440; 1435)}$= -2.514, *p*= 0.011; **Table S2.4**) and there was a significant interaction between test and species (z-value $_{(1440; 1435)}$= 2.761, *p*= 0.006). In both kinds of tests, *C. delalandii* chose more often the hot zones and less often the cold zones than *C. vaillantii*. More importantly, when water was available, *C. vaillantii* shifted space use towards the middle or cold side of the terraria (z-value $_{(720, 717}$= 2.123; *p*= 0.034; **Table S2.4**), but *C. delalandii* did not (z-value $_{(720, 717}$= -1.803; *p*= 0.07; check **Table S2.4**) even though it slightly decreased the use of hot zones when water was unavailable (**Fig. 2.5**). When considering data from both species, there were no significant differences in spacial use among classes (z-value$_{(1440; 1431)}$= 1.145, *p* =0.25). However, *C. delalandii* pregnant females used the cold and middle zones and males the hot zones more often than the the remaining classes (z-value $_{(720, 717}$= 2.122; *p*= 0.034; **Table S2.4**) while in *C. vaillantii* there were no significant differences among classes (z-value $_{(720, 715}$= -1.002; *p*= 0.316).

The three different parts of the body attained significant different temperatures (**Table S2.1** and **S2.3**). The temperature of the head (Th), abdomen (Ta) and tail (Tl) differ significantly between species (t-value Th $_{(480, 90.94)}$= 4.404; *p*< 0.001; t-value Ta $_{(480, 87.02)}$= 4.895; *p*< 0.001; t-value Tl $_{(480, 75.18)}$= 4.639; *p*< 0.001) and classes (t-value Th $_{(480, 83.07)}$= 2.549; *p*= 0.012; t-value Ta $_{(480, 79.39)}$= 2.509; *p*= 0.014; t-value Tl $_{(480, 67.45)}$= 2.267; *p*= 0.027). The interactions between species, zone and those temperatures from males and pregnant females differed significantly with temperatures from non-pregnant females (**Table S2.3**). In general, temperatures were lower in pregnant *C. delalandii* females (Th Fp: 32.56ºC vs Th M: 32.89ºC, Th F: 33.41ºC; Ta Fp: 33.00ºC vs Ta M: 33.92ºC, Ta F: 33.95ºC; Tl Fp: 32.93ºC vs Tl M: 34.11ºC, Tl F: 33.74ºC; Table S1) and *C. vaillantii* males (Th M: 29.72ºC vs Th Fp: 30.85ºC, Th F: 33.09ºC; Ta M: 30.39ºC vs Ta Fp: 31.47ºC, Ta F: 33.73ºC; Tl M: 30.39ºC vs Tl Fp: 31.59ºC, Tl F: 33.77ºC; Table S1).
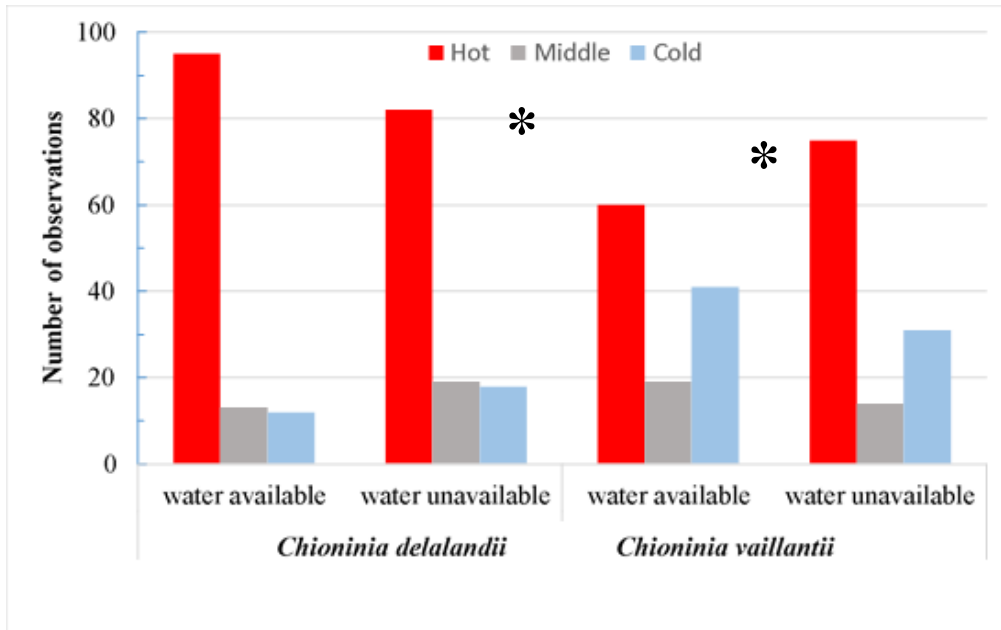
Figure 2.5. Spatial use of thermal gradients by lizards when water is available or unavailable for each species, *C. delalandii* (N=120) and *C. vaillantii* (N=120). Asterisks represent the difference in the spatial use of gradient when water is available between species and between and between tests for *C. vaillantii*. Observations of the 10 individuals of each species were recorded each hour along 12h per test.

2.3.4 Evaporative water loss

In the experiment inside the gradient where lizards could thermoregulate and, eventually, had access to water, *C. vaillantii* lost more mass than *C. delalandii* when accounting to size and initial body mass (SVL and BMi-corrected: $F_{(20,1)}= 13.37$, $p= 0.002$; **Fig. 2.6A**; **Table S2.1** and **S2.5**). Similar results were obtained for $\Delta W/SVL$, with the exception of detection of differences among classes as well in this case (BM-corrected: $F_{(10,2)}= 413.92$, $p< 0.001$; **Table S2.1** and **S2.5**). When water loss was percentual, $\Delta W\%$, no difference between species were detected, but between tests and the interaction between species and test (SVL-corrected $F_{(20,1)}= 13.87$, $p< 0.001$; $F_{(20,1)}= 134.25$, $p< 0.001$, respectively; Table S5).

There was significant difference for the average ΔW of *C. vaillantii* individuals thermoregulating with or without water, losing significantly more BM when water was restricted (SVL and BMi-corrected: $F_{(10,1)}= 57.57$, $p= 0.000$). For this species, there were no significant differences among classes (SVL and initial BM-corrected: $F_{(10,2)}= 1.77$, $p= 0.238$) in ΔW, but there were significant differences in the interaction between class and test (SVL and BMi-corrected: $F_{(10,2)}= 10.26$, $p= 0.000$; **Table S2.5**). Similar results were obtained for $\Delta W\%$ (**Table S2.5**). Pregnant females, on average, loose less BM than non-pregnant females and males in both tests, but males perform worse than the latter when water is available (Water: Fp= -0.72%; F= -2.99%; M= -5.82%; No water: Fp= -1.29%; F= -3.38%; M= -2.63%).

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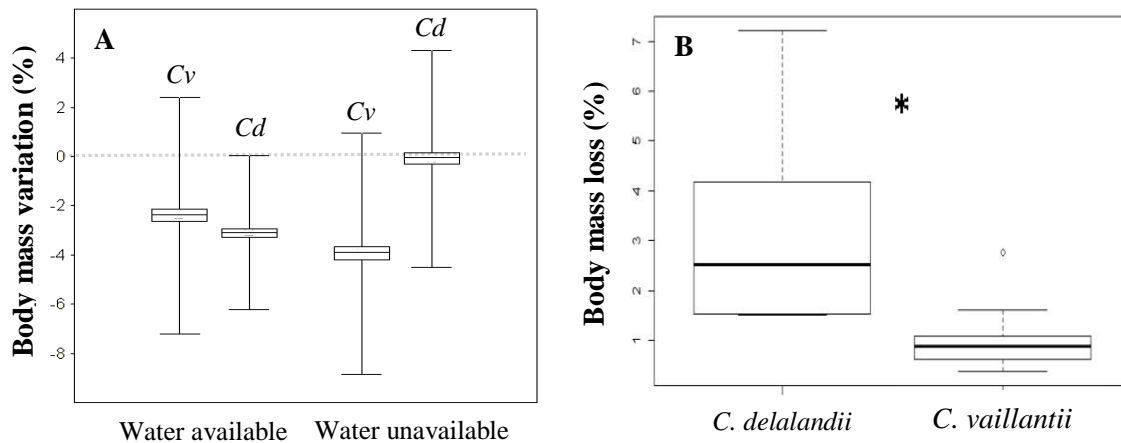
Figure 2.6. Box-and-whiskerplots of the percentage of water loss in the evaporative water loss experiments for *C. vaillantii* (*Cv*) and *C. delalandii* (*Cd*) performed in the terraria allowing thermoregulation (**A**) and in the silica containers (**B**). Mean values are represented by horizonta black lines and standard errors by vertical lines. Asterisks represent the significant diference between species and/ or tests in the experiments.

For *C. delalandii* there was also significant differences for the average ΔW of individuals thermoregulating with or without water, losing significantly less BM when water was restricted (SVL and BMi-corrected: $F_{(10,1)}= 156.09$, $p= 0.000$; **Table S2.5**). There were no differences in ΔW for *C. delalandii* among classes (SVL and BMi-corrected: $F_{(10,2)}= 0.96$, $p= 0.426$), but there were significant difference when the interaction between class and test was considered (SVL and BMi-corrected: $F_{(10,2)}= 10.44$, $p= 0.000$). Similar results were obtained for $\Delta W\%$ (**Table S2.5**). Males and pregnant females lost more BM when water was available than when water was restricted (Water: Fp= -4.13%; F= -1.17%; M= -3.25%; No water: Fp= -0.86%; F= 0.31%; M= 0.22%).

In the evaporative water loss experiment inside the chambers, where lizards were not allowed to thermoregulate, *C. delalandii* lost, on average, more water percentage than *C. vaillantii* ($F_{(20,1)}= 8.32$, $p= 0.01$; **Fig. 2.6B**; **Table S2.1**), but there were no differences between classes within each species ($F_{(20,1)}= 0.002$, $p= 0.96$). On average, *C. vaillantii* lost -1.05% while *C. delalandii* lost -3.06% of BM (**Table S2.1**). When SVL and BMi were used as covariates, the differences between species disappeared (SVL-corrected: $F_{(20,1)}= 0.01$, $p =0.9$; BMi-corrected: $F_{(20,1)}= 1.28$, $p= 0.28$).

2.4 DISCUSSION

As predicted, the different distribution patterns of both congeneric skink species on Fogo, an island with marked environmental gradients but no major geographic barriers, was in accordance

with the divergence in their fundamental niches. Indeed, in sum, our results pointed to a considerable physiological signal constraining their niches. In particular, our results showed a complex interplay between thermal and hydric ecophysiology in adults and, most likely, in embryos.

On Fogo Islans, spatial variation of thermal and hydric environment certainly influenced the probability of occurrence of both species, similarly to what was shown with other species (Carneiro et al., 2015; Carneiro et al., 2017; Carretero et al., 2016; Khifa et al., submitted; Rato & Carretero, 2015), although other factors, such as food availability and habitat structure, may also explain it (Ferreira et al., 2016; Matias & Verrastro, 2018). Moreover, thermal and hydric traits were already identified in a previous study, carried out on São Vicente, a more arid island of the archipelago, as important to understand the distribution patterns of other Cabo Verdean reptile species, including a small skink species, *Choninia stangeri* (Carretero et al., 2016). In that case, a combination of diurnal activity, high preferred temperatures and, mainly, high water loss rates restricted the geographical range of the species to the most humid part of the island, matching with the predictions of correlative ecological niche models (Vasconcelos et al., 2012). In our case, the limited distribution of *C. vaillantii* on Fogo compared to the widespread distribution of *C. delalandii* already suggested higher ecophysiological restrictions in the former. Datta-loggers either identified humidity or temperature as restrictive factors for the occurrence of *C. vaillanti* across sites. Since the southern part of the island has higher temperatures and lower humidity, it was expected *C. vaillantii* to be absent there, considering its poor thermoregulation abilities and its high proportional loss of water when water is restricted. Correlative models previously identified the presence of water habitat as the main environmental factor explaining the presence of *C. vaillantii*, while only lava substrates had some negative influence on the presence of *C. delalandii* (Vasconcelos et al., 2012). In fact, our results show that hydric ecology can be very important for explaining distribution patterns rather than thermal profiles. Thus, it is not surprising that both lizard species differed in their hydric ecophysiology. What is remarkable is that it affected thermoregulation, and that body size alone does not explain those differences. Other studies already confirmed that thermal biology may present more divergence than morphology in close taxa (Hertz et al., 2013).

At a smaller scale, our results also explained why *C. vaillantii* prefers walls to vegetation and big rocks, as those attained lower temperatures and retained more humidity according to our environmental monitoring of representative sites using data-loggers. Walls can also be used has a refuge against predators. On the contrary, microhabitats composed by big rocks are selected by *C. delalandii* probably because of the higher temperatures they attained, since it allows it to thermoregulate faster.

At the species level, *C. delalandii* certainly preferred higher temperatures than *C. vaillantii*, approaching more often to the heat source inside the gradients, while these preferences of space use were only slightly affected by water availability. Considering selected temperatures, when

water was restricted, *C. delalandii* attained lower temperatures than when water was available, constraining the thermoregulation, reducing it activity and avoiding water loss. In contrast, *C. vaillantii* selected lower temperatures than *C. delalandii* in general, which became higher in the absence of water, by remaining more often in the hot zone of the terrarium. This indicates *C. vailantii* as a poorer thermoregulator and suggests that hydroregulation may be taking precedence over thermoregulation in this species, as it is more often looking for water than for ideal temperatures. It has been reported in other species that water restriction affects negatively the thermoregulation, despite of the change of the behaviour from the individuals (Rozen–Rechels et al., 2019). It could be argued that this pattern was a by-product of mobility, that is, that *C. delalandii*, being smaller than *C. vaillantii*, would be more efficient shuttling between hot and cold parts of the gradient to reach optimal temperatures due to a lower surface/ volume relationship (Dillon et al., 2012; Huey, 1982). This would allow better performances of *C. delalandii* (Huey, 1982) without compromising its fitness. Alternatively, for the same reason, *C. delalandii* would need to thermoregulate more often to maximize the heat intake that is lost at a faster pace than *C. vaillantii*, explaining the higher average temperatures and frequencies in the hot zone of the terraria. However, *C. vaillanti* did not show wider thermal variation, but systematically selected lower temperatures than the other species. Some studies support that larger sizes also matter to protect against dehydration (Carretero et al., 2016; Ferreira et al., 2016). But, when we look at the behaviour level in the terraria tests, we can see that *C. vaillantii* does behaves in an unexpected way when water is unavailable, as it keep selecting hotter zones even when water is restricted, what may increase water loss. Similar water-mediated shifts in thermal preferences have been reported in other lizards (Bowker, 1993; Crowley, 1987; Huang et al., 2020; Rozen-Rechels et al., 2020; Sannolo & Carretero, 2019). Also, evidences about the interation of hydric ecology and thermal ecology in lizards where water is restricted only a part of year and temperatures are moderated were reported in the Mediterranean (Carneiro et al., 2015; Carretero & Sillero, 2016; García-Muñoz & Carretero, 2013; Sannolo & Carretero, 2019). However, to our knowledge, this is the first time differences were found between congeneric species and in tropical dry areas.

In arid environments, where precipitation occurs rarely and punctually, little is known how lizards react to lack of water. Considering only our results on selected temperatures, we could hypothesize that *C. delalandii* would be better suited to arid habitats and so, high body temperatures would be better tolerated by this species than by *C. vaillantii*. However, if better suited to arid environments we would expect *C. delalandii* to lose less water than *C. vaillantii* as well. Contrary to expectation, when exposed at low humidity conditions, *C. delalandii* loses proportionally more water than the latter. Thus, when lizards were prevented from thermoregulating, only interspecific differences remained and agreed the biophysical expectations, that is, that the smaller skink lost less evaporative water than the larger species due to the lower surface/volume ratio (Schmidt-Nielsen, 1997). Nevertheless, it is notworthy that, when lizards were allowed to thermoregulate, *C. delalandii* lost less water relative to its body

mass than *C. vaillantii* when water was unavailable. This suggests that differences in the trade-off between thermal and hydric physiology may be more associated with behavioural adjustments than with radical physiological changes. Studies in other lizard groups indicate that behavioural plasticity may buffer physiological adaptation (Muñoz & Losos, 2018), while thermal ecophysiology seems to evolve at a slower pace that hydric physiology (Garcia-Porta et al., 2019). Considering that both *Chioninia* species are sister taxa, and shared a common ancestor 6.9–5.9 Mys ago (Miralles et al., 2010), this may be actually the case. Since they currently overlap in several southern islands in Cabo Verde, it is tempting to conjecture whether ecophysiological differences are the result of character displacement or, in fact, contributed to the speciation process (Ahmadzadeh et al., 2013). All these aspects should be investigated with a broader species and island dataset in a phylogenetic context.

A recent study showed that water restriction increased oxidative stress in lizards (Dupoué et al., 2020a). However, dehydration and chronic water restriction leads to different physiologic responses between sexes (Huang et al., 2020). We could also see different physiological responses among classes of both species. The thermal minimisation of water loss and dependence on availability of water was more marked in pregnant females. These attained lower body temperatures than non-pregnant individuals, so we can predict that it was due to pregnancy. Here, the shift towards higher temperatures were more marked in *C. vaillantii* than *C. delalandii* when water was unavailable, but *C. vaillantii*, pregnant females lost less water comparing to other classes, probably due to surface/ volume ratio, or just because they have more fat content (Cullum, 1998). When water is restricted, some pregnant females species may select cooler temperatures and wetter sites (Rozen–Rechels et al., 2019), as *C. delalandii* but not *C. vaillantii*. Some studies showed that females that maintain the embryos more time during the gestation and manipulating their thermal regimes, enhancing offspring fitness (Shine, 1995; Webb et al., 2006). By modifying their selected temperatures, pregnant females may gain the advantage of providing optimal temperatures for embryo development (Li et al., 2009; Rodríguez-Díaz & Brana, 2011; Shine, 1995). Maintaining lower temperatures at long gestation lengths increase reproductive costs and decrease offspring survival, but at low gestation lengths lower temperatures may be profitable (Li et al., 2009).

Viviparity in *Chioninia* indicates that pregnancy may be imposing additional hydric costs to thermoregulation in females, especially to *C. vaillantii*. Indeed, the existence of a mother-offspring conflict for hydric resources has already been indicated in other viviparous reptiles from the temperate region (Bonnet et al., 2017; Dupoué et al., 2020b). However, the arid conditions on Fogo Island are probably posing stronger environmental pressures than most sub-Saharan and tropical areas were other Mabuyinae skinks occur and, hence, revealing differences between both species. We suggest that not only temperature favoured viviparity in Cabo Verde, but also humidity, as viviparous females may maintain an optimal internal hydric enviroment for embryo development enhancing the fitness of their offspring (Shine, 1995). In fact, recently it was proven that viviparity emerged in the ancestors of *Chioninia*, as most of its continental African relatives

are oviparous (Pereira & Schrago, 2017). So, it is possible that the lack of water, together with the high temperatures, may have driven and maintained this evolutionary path in Cabo Verde skinks.

Overall, our experiments uncovered a substantial ecophysiological background behind the divergent spatial patterns between both skink species on Fogo Island, reinforcing similar reports for other lizards, including from Cabo Verde. In addition, results indicated intrinsic differences in the balance between thermal and hydric physiology, which were mediated by behaviour rather than by morphology, and shifts of that balance due to mother-embryo conflict in these viviparous skinks. These findings may carry profound conservation repercussions and so, Cabo Verde lizards may be used as models to predict the future challenges of other lizard species from other geographical areas. At a global scale, most tropical lizard are especially vulnerable to climate warming (Sinervo et al., 2010). As they evolved under stable thermal conditions, their preferred temperatures are closer to critical thermal maxima and their performance curves decline steeply with higher temperatures (Sinervo et al., 2010). At a local scale, aridification trends evidenced in regions such as the Sahara-Sahel and the Mediterranean basin hotspot, both of which include Cabo Verde (Dai, 2013), will pose an additional threat to those species that are sensitive to dehydration, such as *C. vaillantii*. In fact, its range has probably already been reduced in the past by increasing aridity, as suggested by the finding of subfossil records on Boavista and Maio, both islands much more arid than Fogo and Santiago, and where the species is no longer found (Carranza et al., 2001). Moreover, viviparity in all *Chioninia* species may increase their extinction risk, since viviparous mothers may buffer short-term variations in humidity at the cost of dehydrating themselves in the long-term (Bonnet et al., 2017). Therefore, a suitable management strategy should focus on protecting the spatial heterogeneity across the archipelago, including vegetation, vertical structures and moist microhabitats. In the future, mechanistic models, incorporating thermal and hydric traits, are expected to improve our functional understanding of sedentary ectotherms at different spatial scales, and to provide better predictions of their responses to environmental disturbance and climate change (Huey et al., 2012; Logan et al., 2015; Wang et al., 2016).

2.5 ACKNOWLEDGEMENTS

2.6 REFERENCES

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2.7 SUPLEMENTARY MATERIAL

Table S2.1. Details of the individuals used in the experiments. Code, species, class (M, Male; Fp, Pregnant female; F, Non-pregnant female), body mass (BM) and snout-vent length (SVL) of each individual. The average values of preferred, head, truck and tail temperatures (Tp, Th, Ta and Tl, respectively) and water loss in the terraria (ΔW in grams and $\Delta W\%$ in BM percentage) and silica experiments (WL in grams and WL% in BM percentage) are also given per class and species.

Code	Species	Class	BM	SVL	Tp	Th	Ta	Tl	ΔW	$\Delta W\%$	W/SVL	WL	WL%
FCd06.19.70		F	5.40	6.60	33.70	33.41	33.95	33.74	-0.02	-0.43	0.91	-0.26	-4.58
FCd06.19.69		F	6.68	7.10									
FCd06.19.83		Fp	8.02	6.60	32.83	32.56	33.00	32.93	-0.23	-2.50	1.24	-0.21	-2.43
FCd06.19.81		Fp	9.85	7.50									
FCd06.19.71		Fp	8.21	7.20									
FCd06.19.79	*C. delalandii*	M	7.67	7.00	33.64	32.89	33.92	34.11	-0.10	-1.52	1.06	-0.20	-2.83
FCd06.19.78		M	7.97	7.30									
FCd06.19.77		M	6.42	6.80									
FCd06.19.76		M	7.20	6.80									
FCd06.19.72		M	6.39	6.30									
Total		All	7.38	6.92	33.41	32.89	33.65	33.68	-0.12	-1.59	1.09	-0.22	-3.06
FCv06.19.89		F	31.95	10.20	33.53	33.09	33.73	33.77	-1.01	-3.19	3.25	-0.26	-0.80
FCv06.19.91		F	32.23	10.00									
FCv06.19.96		F	33.03	10.40									
FCv06.19.75		Fp	37.36	11.70	31.30	30.85	31.47	31.59	-0.42	-0.98	4.30	-0.39	-0.91
FCv06.19.92	*C. vaillantii*	Fp	39.40	11.00									
FCv06.19.93		Fp	56.26	12.00									
FCv06.19.74		M	38.50	10.90	30.17	29.72	30.39	30.39	-1.58	-4.80	3.49	-0.48	-1.34
FCv06.19.85		M	56.60	11.00									
FCv06.19.90		M	30.48	10.60									
FCv06.19.94		M	43.86	11.50									
Total		All	39.97	10.93	31.52	31.98	32.68	32.72	-1.06	-3.17	3.66	-0.39	-1.05

Table S2.2. Models for humidity (H) and temperature (T) recorded by the data-loggers tests with the respective degrees of Freedom (df), Akaike information criterion (AIC), likelihood-ratio (L-ratio) and p-values of significant outputs (* stands for p-values< 0.050). The most informative models are signalled with †.

Model	Independent variables	df	AIC	L-ratio	*p*-value
H01†	Date/Time/Site/Microhabitat*	37	25797.2	2320.66	0.000
H02†	Date/Site/Microhabitat*	13	25846.4	2223.49	0.000
H03	Time/Site/Microhabitat*	28	26052.2	2047.65	0.000
H04	Site/Microhabitat*	4	26094.5	1957.39	0.000
H05	Date/Time/Microhabitat*	35	26400.9	1712.95	0.000
H06	Date/Microhabitat*	11	26439.7	1626.10	0.000
H07	Time/Microhabitat*	26	26604.3	1491.59	0.000
H08	Microhabitat*	2	26638.7	1409.18	0.000
H09	Date/Time/Site*	35	27661.7	452.13	0.000
H10	Date/Site*	11	27670.9	394.92	0.000
H11	Time/Site*	26	27768.9	326.93	0.000
H12	Site*	2	27777.8	270.04	0.000
H13	Date/Time*	33	27932.9	176.94	0.000
H14	Date*	9	27941.3	120.50	0.000
H15	Time*	24	28035.8	56.17	0.000
T01†	Date/Time/Site/Microhabitat*	37	19466.0	489.97	0.000
T02†	Time/Site/Microhabitat*	28	19570.5	367.54	0.000
T03†	Date/Time/Site*	35	19571.9	380.13	0.000
T04†	Date/Site/Microhabitat*	13	19591.8	316.14	0.000
T05	Date/Time/Microhabitat*	35	19631.3	320.66	0.000
T06	Time/Site*	26	19671.8	262.15	0.000
T07	Date/Time*	33	19677.9	270.07	0.000
T08	Site/Microhabitat*	4	19686.7	203.29	0.000
T09	Date/Site*	11	19692.0	211.89	0.000
T10	Time/Microhabitat*	26	19733.5	200.48	0.000
T11	Date/Microhabitat*	11	19746.8	157.23	0.000
T12	Time*	24	19777.7	152.73	0.000
T13	Site*	2	19783.2	102.76	0.000
T14	Date*	9	19791.1	108.88	0.000
T15	Microhabitat*	2	19840.0	45.94	0.000

Table S3.3. Models for the preferred temperature. The model codes (T, both species; TCv, *Chioninia vaillantii*; TCd, *Chioninia delalandii*) and the variables used (Tp, prefered body temperature; Th, head temperature; Ta, abdominal temperature; Tl, tail temperature; Sp, species; Test: with or without water; Zone: hot, middle or cold; Class: male, pregnant female or non-pregnant female; Preg: pregnant or non-pregnant individual; Body, body part: head, abdomen or tail) are detailed. Akaike information criterion (AIC), and coefficients, standard errors and p-values of significant outputs (* stands for p-values< 0.050) are also given. The most informative models are signalled with †.

Code	Variables	AIC	Output	*p*-value	Coef	SE
T1†	Tp ~ Sp * Test *	6902.5	Sp*	0.000	4.431	1.563
	Zone * Class +		Test	0.242		
	(1|Code)		Area*	0.000	4.002	0.992
			Class*	0.011	2.628	1.172
			Sp/Test	0.599		
			Sp/Zone*	0.000	-7.266	0.607
			Test/Zone	0.161		
			Sp/Class*	0.001	-3.327	0.760
			Test/Class	0.866		
			Zone/Class*	0.000	-4.015	0.456
			Sp/Test/Zone	0.840		
			Sp/Test/Class	0.147		
			Sp/Zone/Class*	0.000	4.795	0.294
			Test/Zone/Class	0.665		
			Sp/Test/Zone/Class	0.265		
T2†	Tp ~ Sp * Zone	6937.3	Class*	0.003	3.166	0.999
	* Class +		Zone*	0.000	4.533	0.821
	(1|Code)		Sp*	0.000	5.729	1.342
			Class/Zone*	0.000	-5.288	0.373
			Sp/Class*	0.000	-4.755	0.656
			Zone/Sp*	0.000	-10.282	0.489
			Sp/Zone/Class*	0.000	7.580	0.237
T3	Tp ~ Test *	6972.7	Test*	0.010	2.575	1.892
	Zone * Class *		Zone*	0.007	-2.661	0.745
	Body + (1|Code)		Class	0.963		
			Body*	0.014	2.440	0.619
			Test/Zone*	0.001	-3.221	1.034
			Test/Class*	0.015	-2.414	0.923
			Zone/Class	0.685		
			Test/Body	0.697		
			Zone/Body	0.117		
			Class/Body	0.224		
			Test/Zone/Class*	0.007	2.665	0.512
			Test/Zone/Body	0.795		
			Test/Class/Body	0.638		
			Zone/Class/Body	0.463		

			Test/Zone/Class/Body	0.784		
T4	Tp ~ Test * Zone * Class + (1|Code)	6985.9	Test*	0.000	5.665	0.740
			Zone*	0.000	-9.977	0.306
			Class	0.071		
			Test/Zone*	0.000	-7.572	0.407
			Test/Class*	0.000	-5.061	0.361
			Zone/Class*	0.007	2.666	0.147
			Test/Zone/Class*	0.000	6.123	0.201
T5	Tp ~ Sp * Test * Zone * Body + (1|Code)	6991.2	Sp	0.054		
			Test	0.377		
			Zone	0.276		
			Body	0.379		
			Sp/Test	0.502		
			Sp/Zone*	0.003	-2.914	0.665
			Test/Zone	0.498		
			Sp/Body	0.923		
			Test/Body	0.932		
			Zone/Body	0.624		
			Sp/Test/Zone	0.776		
			Sp/Test/Body	0.879		
			Sp/Zone/Body	0.906		
			Test/Zone/Body	0.965		
			Sp/Test/Zone/Body	0.985		
T6	Tp ~ Sp * Test * Zone + (1|Code)	7001.8	Sp*	0.000	3.930	0.628
			Test*	0.038	2.067	1.025
			Zone	0.102		
			Sp * Test	0.172		
			Sp * Zone*	0.000	-7.566	0.265
			Test/Zone	0.067		
			Sp/Test/Zone	0.441		
T7	Tp ~ Test * Zone * Preg * Body + (1|Code)	7045.5	Test	0.067		
			Zone*	0.000	-4.157	0.406
			Preg	0.954		
			Body*	0.002	3.078	0.321
			Test/Zone*	0.014	-2.452	0.559
			Test/Preg	0.063		
			Zone/Preg	0.975		
			Test/Body	0.800		
			Zone/Body	0.055		
			Preg/Body	0.332		
			Test/Zone/Class	0.103		
			Test/Zone/Body	0.881		
			Test/Preg/Body	0.541		
			Zone/Preg/Body	0.592		
			Test/Zone/Preg/Body	0.800		
T8	Tp ~ Class * Zone + (1|Code)	7048.7	Class*	0.000	-4.395	0.372
			Zone*	0.000	-18.945	0241
			Class/ Zone*	0.000	8.337	0.118

T9	Tp ~ Sp * Test * Body + (1|Code)	7628.7	Sp	0.417		
			Test	0.181		
			Body	0.364		
			Sp/Test	0.062		
			Sp/Body	0.857		
			Test/Body	0.978		
			Sp/Test/Body	0.986		
T10	Tp ~ Sp * Test + (1|Code)	7632.5	Sp	0.290		
			Test*	0.000	3.598	0.555
			Sp/Test*	0.000	-4.878	0.351
T11	Tp ~ Sp * Test * Preg + (1|Code)	7639.7	Sp	0.331		
			Test*	0.001	3.255	0.663
			Preg	0.746		
			Sp/Test*	0.000	-4.408	0.419
			Sp/Preg	0.889		
			Test/Preg	0.656		
			Sp/Test/Preg	0.552		
T12	Tp ~ Test * Class + (1|Code)	7658.1	Test*	0.011	-2.535	0.422
			Class	0.909		
			Test/Class	0.193		
T13	Tp ~ Test * Preg + (1|Code)	7659.4	Test*	0.003	-2.907	0.211
			Preg	0.580		
			Test/Preg	0.709		
T14	Tp ~ Sp * Class	7665.5	Sp	0.091		
			Class	0.398		
			Sp/Class	0.332		
T15	Tp ~ Sp * Preg	7666.2	Sp	0.082		
			Preg	0.680		
			Sp/Preg	0.801		
T16†	Th ~ Sp * Zone * Class + (1|Code)	2353.2	Sp*	0.000	4.404	1.676
			Zone*	0.008	2.641	1.432
			Class*	0.012	2.549	1.222
			Sp/Zone*	0.000	-5.601	0.843
			Sp/Class*	0.000	-3.457	0.808
			Zone/Class*	0.007	-2.673	0.646
			Sp/Zone/Class*	0.000	3.759	0.402
T17	Th ~ Sp * Test * Zone + (1|Code)	2366.4	Sp*	0.002	3.080	0.875
			Test	0.161		
			Zone	0.131		
			Sp * Test	0.285		
			Sp * Zone*	0.000	-4.653	0.458
			Test/Zone	0.229		
			Sp/Test/Zone	0.518		
T18	Th ~ Test * Zone * Preg + (1|Code)	2390.4	Test*	0.013	2.471	0.668
			Zone*	0.000	-7.362	0.287
			Preg	0.697		
			Test/Zone*	0.000	-3.437	0.382
			Test/Preg*	0.031	-2.152	1.200

			Zone/Preg	0.801		
			Test/Zone/Preg*	0.004	2.026	0.683
T19†	Ta ~ Sp * Zone * Class + (1|Code)	2318.0	Sp*	0.000	4.895	1.616
			Zone*	0.006	2.710	1.380
			Class*	0.014	2.509	1.179
			Sp/Area*	0.000	-6.291	0.812
			Sp/Class*	0.000	-3.803	0.779
			Zone/Class*	0.003	-2.964	0.623
			Sp/Zone/Class*	0.000	4.321	0.387
T20	Ta~ Sp * Test * Zone * + (1|Code)	2342.5	Sp*	0.002	3.123	0.853
			Test	0.301		
			Zone	0.311		
			Sp /Test	0.531		
			Sp /Zone*	0.000	-4.805	0.447
			Test/Zone	0.361		
			Sp/Test/Zone	0.758		
T21	Ta ~ Test * Zone * Preg + (1|Code)	2368.7	Test*	0.019	2.343	0.654
			Zone*	0.000	-9.345	0.280
			Preg	0.220		
			Test/Zone*	0.000	-3.363	0.373
			Test/Preg	0.083		
			Zone/Preg	0.392		
			Test/Zone/Preg	0.069		
T22†	Tl ~ Sp * Zone * Class + (1|Code)	2331.2	Sp*	0.000	4.639	1.709
			Zone*	0.012	2.526	1.399
			Class*	0.027	2.267	1.249
			Sp/Zone*	0.000	-6.291	0.826
			Sp/Class*	0.000	-3.674	0.827
			Zone/Class*	0.002	-3.025	0.632
			Sp/Zone/Class*	0.000	4.539	0.395
T23	Tl~ Sp * Test *Zone * + (1|Code)	2361.5	Sp*	0.002	3.056	0.879
			Test	0.282		
			Zone	0.449		
			Sp/Test	0.509		
			Sp /Zone*	0.000	-4.683	0.456
			Test/Zone	0.312		
			Sp/Test/Zone	0.674		
T24	Tl~ Test * Zone * Preg + (1|Code)	2382.0	Test*	0.031	2.157	0.662
			Zone*	0.000	-9.911	0.284
			Preg	0.108		
			Test/Zone*	0.001	-3.276	0.378
			Test/Preg	0.147		
			Zone/Preg	0.253		
			Test/Zone/Preg	0.067		
TCv0†	Tp ~ Test * Zone * Class * Body + (1|Code)	3402.2	Test	0.064		
			Zone*	0.000	-4.009	0.924
			Class	0.220		
			Body	0.074		

			Test/Zone*	0.020	-2.328	1.308
			Test/Class*	0.033	-2.130	1.344
			Zone/Class	0.131		
			Test/Body	0.837		
			Zone/Body	0.178		
			Class/Body	0.404		
			Test/Zone/Class*	0.026	2.226	0.664
			Test/Zone/Body	0.865		
			Test/Class/Body	0.735		
			Zone/Class/Body	0.545		
			Test/Zone/Class/Body	0.839		
TCv1†	Tp ~ Test * Zone * Class + (1|Code)	3403.0	Test*	0.000	4.264	1.112
			Zone*	0.000	-12.367	0.391
			Class*	0.008	-2.931	0.684
			Test/Zone*	0.000	-5.549	0.512
			Test/Class*	0.000	-4.657	0.524
			Zone/Class	0.000	4.851	0.204
			Test/Zone/Class*	0.000	5.214	0.259
TCv2	Tp ~ Test * Class + (1|Code)	3962.4	Test*	0.000	-5.087	0.681
			Class	0.891		
			Test/Class*	0.001	3.264	0.328
TCv3	Tp ~ Test * Class * Body + (1|Code)	3966.0	Test	0.114		
			Class	0.816		
			Body	0.438		
			Test/Class	0.412		
			Test/Body	0.710		
			Class/Body	0.809		
			Test/Class/Body	0.653		
TCv4	Tp ~ Test * Preg + (1|Code)	3972.9	Test*	0.000	-4.687	0.328
			Preg	0.813		
			Test/Preg	0.536		
TCd0†	Tp ~ Test * Zone * Class + (1|Code)	3486.2	Test*	0.000	3.328	1.155
			Zone	0.335		
			Class	0.117		
			Test/Zone*	0.001	-3.151	0.831
			Test/Class*	0.010	-2.555	0.534
			Zone/Class*	0.031	-2.151	0.208
			Test/Zone/Class*	0.016	2.418	0.361
TCd1†	Tp ~ Test * Zone * Class * Body + (1|Code)	3486.8	Test	0.112		
			Zone	0.697		
			Class	0.154		
			Body	0.107		
			Test/Zone	0.149		
			Test/Class	0.187		
			Zone/Class	0.234		
			Test/Body	0.736		
			Zone/Body	0.411		
			Class/Body	0.383		

			Test/Zone/Class	0.233
			Test/Zone/Body	0.804
			Test/Class/Body	0.713
			Zone/Class/Body	0.691
			Test/Zone/Class/Body	0.776
TCd2	Tp ~ Test * Class * Body + (1|Code)	3607.8	Test	0.447
			Class	0.563
			Body	0.057
			Test/Class	0.517
			Test/Body	0.938
			Class/Body	0.257
			Test/Class/Body	0.893
TCd3	Tp ~ Test * Class + (1|Code)	3610.7	Test	0.071
			Class	0.371
			Test/Class	0.170
TCd4	Tp ~ Test * Preg + (1|Code)	3611.2	Test	0.235
			Preg	0.070
			Test/Preg	0.860

Table S2.4.. Models for spatial use of the gradient. The variables used (Sp, species; Test: with or without water; Class: male, pregnant female or non-pregnant female; Preg, pregnant or non-pregnant individual), Akaike information criterion (AIC), outputs and p-values of significant outputs (* stands for p-values< 0.050) are also given. Significant outputs have the respective coefficient (Coef) and standard error (SE). The most informative models are signalled with †.

Code	Variables	AIC	Output	*p*-value	Coef	SE
A0†	Zone ~ Sp * Test + (1|Code)	3761.3	Sp	0.484		
			Test*	0.011	-2.514	0.138
			Sp/Test*	0.005	2.761	0.084
A1†	Zone ~ Sp * Test * Class + (1|Code)	3763.5	Sp	0.118		
			Test*	0.039	-2.057	0.325
			Class	0.252		
			Sp/Test*	0.020	2.316	0.199
			Sp/Class	0.179		
			Test/Class	0.272		
			Sp/Test/Class	0.204		
A2	Zone ~ Sp * Class + (1|Code)	3765.0	Sp*	0.006	2.725	0.355
			Class	0.080		
			Sp/Class*	0.042	-2.032	0.112
A3	Zone ~ Sp * Test * Class + (1|Code) + (1|Hour)	3765.1	Sp	0.118		
			Test*	0.040	-2.052	0.325
			Class	0.251		
			Sp/Test*	0.020	2.311	0.199
			Sp/Class	0.178		
			Test/Class	0.274		
			Sp/Test/Class	0.206		
A4	Zone ~ Sp * Test * Preg + (1|Code)	3767.9	Sp	0.260		
			Test*	0.049	-1.964	0.167
			Preg	0.334		
			Sp/Test*	0.023	2.273	0.102
			Sp/Preg	0.342		
			Test/Preg	0.860		
			Sp/Test/Preg	0.991		
A5	Zone ~ Sp * Test * Preg + (1|Code) + (1|Hour)	3769.5	Sp	0.259		
			Test*	0.049	-1.963	0.167
			Preg	0.333		
			Sp/Test*	0.023	2.272	0.102
			Sp/Preg	0.340		
			Test/Preg	0.858		
			Sp/Test/Preg	0.984		
A6	Zone ~ Sp * Test * Class + (1|Hour)	3821.1	Sp*	0.006	2.743	0.142
			Test*	0.038	-2.069	0.326
			Class	0.062		
			Sp/Test*	0.020	2.326	0.201
			Sp/Class*	0.029	-2.176	0.070
			Test/Class	0.264		

			Sp/Test/Class	0.196		
ACd0†	Zone ~ Class + (1|Code)	1804.9	Class*	0.033	2.122	0.036
ACd1†	Zone ~ Test * Class+ (1|Code)	1805.2	Test	0.165		
			Class	0.282		
			Test/Class	0.495		
ACd2†	Zone ~ Test + (1|Code)	1805.3	Test	0.071		
ACd3†	Zone ~ Preg + (1|Code)	1806.5	Preg	0.124		
ACd4	Zone ~ Test * Preg + (1|Code)	1807.1	Test	0.204		
			Preg	0.158		
			Test/Preg	0.709		
ACv0†	Zone ~ Test + (1|Code)	1950.1	Test*	0.033	2.123	0.056
ACv1†	Zone ~ Test * Class+ (1|Code)	1951.0	Test	0.056		
			Class	0.316		
			Test/Class	0.264		
ACv2	Zone ~ Class + (1|Code)	1952.8	Class	0.154		
ACv3	Zone ~ Test * Preg + (1|Code)	1953.6	Test*	0.045	2.002	0.066
			Preg	0.666		
			Test/Preg	0.702		
ACv4	Zone ~ Preg + (1|Code)	1954.3	Preg	0.566	-0.573	0.209

Table S2.5. Results of the tests for body mass variation using different independent variables. The model codes (for both species; Cv, *Chioninia vaillantii*; Cd, *Chioninia delalandii*) and the variables used (ΔW, body mass variation in water in grams, ΔW% in percentage of the initial BM, BMi, and ΔW/SVL, balanced per snout-vent length, SVL; Sp, species; Test: with or without water; Class: male, pregnant female or non-pregnant female) are detailed. The covariables used were SVL and BMi for ΔW, SVL for ΔW% and BMi for ΔW/SVL). The degrees of freedom (df) and *p*-values (* stands for *p*-values< 0.050) are also given with the respective coefficient (Coef).

Code	Variables	df	*p*-value	Coef
ΔW01	Test *	1	0.000	19.809
ΔW02	Sp*	1	0.002	13.377
ΔW03	Class	2	0.301	1.306
ΔW04	Test/Sp*	1	0.000	102.127
ΔW05	Test/Class*	2	0.000	7.548
ΔW06	Sp/Class	2	0.151	2.167
ΔW07	Test/ Sp/Class*	2	0.000	12.371
ΔW08	Ind. Code*	14	0.000	45.084
ΔWCv1	Test*	1	0.000	57.574
ΔWCv2	Class	1	0.238	1.770
ΔWCv3	Test/Class*	2	0.000	10.265
ΔWCv4	Ind. Code*	7	0.000	46.958
ΔWCd1	Test*	1	0.000	156.099
ΔWCd2	Class	1	0.426	0.964
ΔWCd3	Test/Class*	2	0.000	10.044
ΔWCd4	Ind. Code*	7	0.000	36.654
ΔW%01	Test *	1	0.000	13.873
ΔW%02	Sp	1	0.142	2.411
ΔW%03	Class	2	0.498	0.731
ΔW%04	Test/Sp*	1	0.000	134.255
ΔW%05	Test/Class	2	0.068	2.689
ΔW%06	Sp/Class	2	0.153	2.151
ΔW%07	Test/ Sp/Class*	2	0.000	12.091
ΔW%08	Ind. Code*	14	0.000	26.399
ΔW%Cv1	Test*	1	0.000	25.073
ΔW%Cv2	Class	2	0.178	2.226
ΔW%Cv3	Test/Class*	2	0.000	8.897
ΔW%Cv4	Ind. Code*	7	0.000	22.827
ΔW%Cd1	Test*	1	0.000	152.757
ΔW%Cd2	Class	2	0.602	0.544
ΔW%Cd3	Test/Class*	2	0.007	4.970
ΔW%Cd4	Ind. Code*	7	0.000	32.136
ΔW/SVL01	Test *	1	0.000	29837.212
ΔW/SVL02	Sp*	1	0.000	413.920
ΔW/SVL03	Class*	2	0.002	9.527
ΔW/SVL04	Test/Sp*	1	0.000	9106.585
ΔW/SVL05	Test/Class*	2	0.000	8869.998
ΔW/SVL06	Sp/Class	2	0.090	2.863
ΔW/SVL07	Test/ Sp/Class*	2	0.000	4723.945

ΔW/SVL08	Ind. Code*	14	0.000	192898.414
ΔW/SVLCv1	Test*	1	0.000	74039.282
ΔW/SVLCv2	Class	2	0.031	5.917
ΔW/SVLCv3	Test/Class*	2	0.000	26765.741
ΔW/SVLCv4	Ind. Code*	7	0.000	773513.539
ΔW/SVLCd1	Test	1		
ΔW/SVLCd2	Class*	2	0.002	16.497
ΔW/SVLCd3	Test/Class	2		
ΔW/SVLCd4	Ind. Code	7		

3. MANUSCRIPT II

Shooting skinks for good: producing a film improves attitudes towards a threatened species

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Abstract

Despite its importance in food chains and ecosystem services, reptiles are often negatively influenced by folklore and beliefs, resulting in fear and persecution. In this scenario, Education for Sustainable Development (ESD) may contribute for children to develop positive attitudes (feelings and actions) towards nature and in particular towards reptile conservation. Some studies showed that watching wildlife videos improves attitudes of people towards wildlife. However, few information is available on the impact of engaging people in movie production in their attitudes and perceptions on biodiversity.

Here we propose a project-based learning outreach activity implemented with Cabo Verdean high-school students and planned to improve their perceptions, knowledge and attitudes towards reptiles in general, and the threatened endemic species *C. vaillantii* in particular. We asked students to write a script, shoot and produce a short film that could improve the knowledge and attitudes of their community towards this endemic species. This movie was then presented to the community in a public event. To evaluate the impact of the activity on students, they were asked to fill in two questionnaires, before and after the activity. Our results showed significant increase of positive feelings of students about the reptiles, and increased perception of their importance, and of positive actions towards *C. vaillantii* from pre to post test. These changes in feelings and actions were related to *C. vaillantii* and the production of the film, changes in perceptions, and increased knowledge about reptiles. These findings suggest that movie production may facilitate the ESD, contributing to foster positive public attitudes towards species conservation by increasing emotional connections.

3.1 INTRODUCTION

As we are moving to a sixth mass extinction, there are increased concerns about conservation of resources and how to pursuit more effective ways of conserving biodiversity (Barnosky et al., 2011). It is important to change the perception of people about nature and environment before it is too late to halt massive biodiversity loss. Perception includes some concepts such as beliefs, values, knowledge, motivations, and preferences (Bennett, 2016). Attitudes (consider here as feelings and actions) are constructs central to understanding how people behave (Winter et al., 2005). These can be measured directly by posing questions to responders or indirectly by studying their responses to certain situations (Bohner & Dickel, 2011). Feelings are mental representations of the physiological changes that characterize emotions; this is, a patterned collection of neural and chemical responses produced by the brain when it detects a stimulus, such as an object or situation (Damasio, 2001). Action, on the other hand, are instances of a certain relation, the relation of making happen, whose terms are agents and events (Bach, 1980).

The way people evaluate positively or negatively conservation actions depends on perceptions (Bennett, 2016). Social impacts, ecological outcomes, legitimacy of conservation governance, and acceptability of conservation management are four categories included in perception proposed by Bennett (2016) that can improve conservation policies and practices. To promote species conservation and change individual attitudes we need not only to give people more and intelligible information, promote sensitivity and awareness, but also increase the emotional connection with the subjects of conservation actions (Miralles et al., 2019; Skibins & Powell, 2013). Evidence supports that contacting with nature in the childhood increase environmental awareness in adulthood (Wells & Lekies, 2006). Other studies showed that direct experiences with nature immediately increased understanding and willingness of people to protect biodiversity (Ballouard et al., 2012; Beery & Jørgensen, 2018; Miller, 2007; Prokop & Tunnicliffe, 2008; Randler et al., 2012; Tomažič, 2011). However, contact of children with nature is also decreasing, as well as their sensibility of the value of the natural world (Soga et al., 2016). This highlights the need for schools to promote educational activities that engage students with nature.

Reptiles are important predators, preys, food resources, seed dispersers, pollinators (Godínez-Álvarez, 2004), bioindicators (Read, 1998), and sources of medicines (Alves et al., 2008). The conservation of reptiles is therefore crucial for the balance of the ecosystems and for economic and social benefits. Unfortunately, reptiles are often negatively influenced by folklore and misconceptions, resulting in fear and persecution (Ceríaco et al., 2011) causing problems for the protection of these organisms. And, in fact, this is problematic as 19% of the reptiles are threatened in the world (Böhm et al., 2013). So, Education for Sustainable Development (ESD) is needed to achieve conservation goals. Within the reptiles group, many studies shows that snake-like organisms, such as skinks, suffers most from these threats (Prokop & Tunnicliffe, 2008). Species with snake-like body are the most feared or disgusted, and thus more susceptible to persecution (Janovcová et al., 2019) In children, this is connect with likeability and so, if children like an animal they are more

prone to protect him (Ballouard et al., 2013). In Cabo Verde, reptiles are threatened by many factors such as introduced species, climate change, but also persecution (Marco et al., 2011; Vasconcelos et al., 2013). Despite of the numerous campaigns promoting the conservation of reptiles in Cabo Verde (Marco et al., 2011; Monzón-Argüello et al., 2010), these have focused in the marine realm and none on terrestrial reptiles. However, persecution and introduced species are probably the cause of the extinction of an endemic and emblematic terrestrial species of Cabo Verde, the giant skink of Cabo Verde *Chioninia coctei* (Vasconcelos et al., 2015). Fogo is one of islands with higher reptile diversity in Cabo Verde, and also presents endemic threatened reptiles (Vasconcelos et al., 2013). One example is *Chioninia vaillantii*, classified as Endangered according with IUCN Red List (Vasconcelos, 2013). Due to competition with farmers for fruits, this species can be threatened by persecution (Vasconcelos 2013), and it is feared and disgusted by the community in general due to its large size and its snake-like body.

ESD is fundamental to promote sustainable and healthy approaches for the new generations (Davis, 2008). It is in childhood that humans develop some of their values, attitudes, skills, behaviours and habits (Samuelsson & Kaga, 2008). ESD is important because it relates environment, economy and society promoting the understanding about what is sustainability, and how it can be implemented in the society (Tilbury & Stevenson, 2002). Social factors are important in wildlife-human conflicts, but these are barely considered (Dickman, 2010). These social factors include social media, folklore, expectations and beliefs and can affect and influence the attitude of people towards animals (Alves et al., 2012; Ballouard et al., 2011; Ceriaco, 2012). It is thus important to understand and develop methodologies to change people attitudes towards animals in order to engage locals in conservation efforts. Project-based learning (PBL) is a model that promotes learning while engaging students in projects (Johnson & Delawsky, 2013; Rotgans & Schmidt, 2011). Educators usually act as supervisors and guiders fostering discussions of students and informed decisions before they start implementing each part of the project (Ferreira & Trudel, 2012). Students have the opportunity to create and/or to investigate about projects with outcomes that are seen as important for them and/or for their community (Ferreira & Trudel, 2012). The focus is to foster learning of students about something by asking questions, researching, sharing information and discussing to produce effective products (Tarhan & Acar, 2007). The projects are usually planned to address challenging questions or problems that involve decision-making, investigation, solving tasks, etc. These projects allow students to work autonomously and as a team resulting in meaningful products and learning (Vogler et al., 2018). The main goal is to improve the ability of students to think on other ways, and to learn about subjects (Bell, 2010). Moreover, PBL is a good model to improve emotional and cognitive engagement in students (Sunderland, 2014) and to raise environmental awareness (Alwi et al., 2012). With the increased use of the internet, more people is seeking for online videos, including educational videos (Gilroy, 2010). Although wildlife films are becoming popular these mainly focus on charismatic animals, like primates, and fail to engage locals in local conservation (Wright, 2010). Previous studies showed that films are good to engage local populations and change their attitudes

(Bahk, 2010; Breuer et al., 2017; Wright, 2010), but there no studies are available on how movie production affects attitudes towards endemic animals and change perceptions of locals towards them.

Thus, our goals was to know if an ESD activity using a PBL approach that engaged high school students in a movie production, affects their feelings and actions about terrestrial reptiles in general, and the endemic skink species, the Vaillant's skink *C. vaillantii* in particular. Our main hypotheses were that our approach would impact students: 1) feelings about reptiles; 2) actions towards reptiles; and 3) perceptions about *C. vaillantii's* importance.

3.2 MATERIALS AND METHODS

The study took place from May 2019 to December 2019. The educational activity and impact assessment were performed in five sessions during four weeks in May and June 2019, at a high school on Fogo Island, Cabo Verde. A total of 29 students of 35 students (14 boys and 15 girls), from 14 to 21 years old, from 9th, 10th, 11th grades participate in this activity. We have obtained informed consents from their parents (or legal tutors), from the school director and teachers that allowed the students to participate in this study. The study was approved by a local ethical committee, constituted by a non-governmental organization executive director, the representative of the "Direcção Nacional do Ambiente" on Fogo Island, the project leader and the principal investigator of this study. We did not collect personal information and all the questionnaires and records were identified with a code to keep the anonymity of the answers of the students. All students volunteered to participate in this study and were free to quit whenever they wanted.

3.2.1 Educational activity

The students were asked to write a script, shoot and produce a short film that could improve the knowledge, attitudes and perceptions of their community towards *Chioninia vaillantii*. This movie was then presented to the community in a public event. In the first session, that lasted 90 minutes, after the pre-test questionnaires (see below), we made a brief presentation about reptiles: how they are taxonomically classified, the species of reptiles that occur in Cabo Verde and Fogo Island (with no details on the target species), and potential threats to their conservation. The main goal of the presentation was to present the context of the study object to students, fostering their curiosity. In the second session, that lasted one hour, students discussed and proposed the movie script. Students were asked to collaboratively propose, discuss and decide about the duration of the movie, the focal points to mention and their order in the film. Similarly, students were asked to decide on how the movie would be constructed. Decision of student also included how, where, when and what would be recorded. Students divided into groups chosen by themselves to record each part of the film. The script was set in a collaborative manner with all students that participated in the study. Based on the discussion and decisions made, students were instructed to record portions of the film with their

mobile phones. As some students asked to see the species, in the third session one individual was temporarily caught and presented in the class, for students to take pictures and make records. The animal was released in the same spot where it was caught at the end of the session. During this session, students provided the research team the parts of the movie they have recorded for final editing. Since none of the students had movie editing skills, a research team member edited the movie exactly as students discussed during the previous sessions (in terms of order and length).

In the fourth session, students presented the movie to the whole community in the school auditorium. The students took care of all the publicizing of the event: they spoke with colleagues, professors and parents, and set up posters around the school and at the school entrance. The goal of this presentation was to raise awareness in the local population to the problem of conservation of reptiles, and specifically of *C. vaillantii*. The presentation also aimed to highlight the importance of the work of the students the community. Approximately 200 people were present at the video presentation.

3.2.2 Impact assessment

The first phase occurred on May 14 before the activity during the first session above described. Students were asked to fill in a paper-and-pencil questionnaire (pre-test herein) to evaluate their knowledge and perceptions of reptiles in general and *C. vaillantii* in particular. The maximum time students took to complete the questionnaire was one hour, but there was no time limit. As direct attitude can be measures by single item numeric response scales or multi-item scales, such as the frequently employed Likert scale (Winter et al., 2005), the questionnaire consisted of four questions (Q; Appendix 3.1). The Q1 aimed to evaluate what students felt towards reptiles, expressed in one word. The Q2 was a Likert scale to describe how students felt when they saw a reptile. The Q3 was a short answer describing the actions of the students when they saw reptiles; and Q4 a Likert scale to evaluate the importance attributed by students to *C. vaillantii*.

To complement the information collected in the pre-test, individual interviews were performed (by RV) to each student in a separate room in the following weeks. The interviews were conducted in Portuguese or Cabo Verdean Creole, according to the preference of the interviewed, and recorded for further analyses. The interviews were used to inform the set the categories of analysis for the content analysis of the answer of students to the questionnaire and to support their classification.

After the public presentation of the movie, students were asked to fill in a second questionnaire (post-test herein; **Table S3.1**). Although Cabo Verdean students speak Portuguese at school, Cabo Verde Creole native/ fluent speaker accompanied the research team during the application of the questionnaires members and the interviews to ensure the understanding and effective communication.

Open questions about feelings – defined according to Damásio (2001) – and actions – defined according Bach (1980) – were analysed through a content analysis (Merriam, 2015) carried out by two members of the research team. The categories were created based on the literature (Ballouard et

al., 2012; Ceríaco & Marques, 2013) and on the free floating reading of the answer of student answers to the questionnaire and interviews. After creating the categories of analysis for each question, two team members individually analysed all the answers. The reliability of the results was obtained by the percentage of agreement between the individual analyses (McHugh, 2012). In the cases team members did not agree how to categorize an answer, the answer was excluded from the analysis.

The video contents were transcribed (translated transcription available in Appendix 2) and we a content analysis of the video transcription was performed to identify what aspects the students considered most important to approach and communicate to the public, as well as learnings and experiences of students. The categories were created based on the literature (Ballouard et al., 2012; Tomažič, 2011) on the free floating reading of the video transcriptions and images. After creating the categories of analysis for each question, two team research members individually analysed the entire video. In the cases where the evaluators did not agree, the information was excluded from further analysis.

3.3.3 Statistical analysis

To evaluate what students have learned about reptiles and *C. vaillantii* and to test if their perceptions changed with this activity we first used Shapiro-Wilks to test for normality in the answers of the four questions. All values were significant for Shapiro-Wilks tests (first question: W=0.861, p=0.000; second question: W=0.809, p=0.000; third question: W=0.799, p=0.000; forth question: W=0.758, p=0.000), thus supporting the non-normality of the data. Given this, we used a non-parametric test, the Wilcoxon Matched Pair Tests test, to test for the differences between pre and post-test. We also performed Spearman's rank correlation between all questions. All tests were performed using Statistica software (Dell, 2016).

3.3 RESULTS

For open questions, the percentage of reliability obtained in the individual analyses was above 95% in all four questions. The categories of analysis set after the literature review and free-floating reading, the criteria used to assign answers to a category and typical answers, are presented in **Table 3.1** for Q1 and **Table 3.2** for Q3.

Answers to the feeling question (Q1) were assigned to four categories－fear, indifference, curiosity and happiness (**Table 3.1**); There were significant differences in students feeling about reptiles in the one-word answer (Q1) before and after the activity ($Z_{(1,57)}= 6.56$, p= 0.00). Students chose more frequently happiness feelings and less fear or sickness feelings in the post-test than in the pre-test (**Fig. 3.1A**). In the Likert scale question (Q2), there were also significant differences before and after the activity ($Z_{(1,58)}= 6.62$, p= 0.00). Students chose more frequently positive feelings to describe what

they felt about reptiles in the post-test than in the pre-test, and negative feelings decreased in the post-test (**Fig. 3.1B**).

Table 3.1. Categories of analysis resulting from the literature review and free-floating reading of the answers of students to the question on feeling about reptiles in the one-word (Q1), assignment criteria to each category and examples of their answers assigned to each category.

Criteria	Definition	Example
Fear or sickness	Being afraid of something as likely to be dangerous, painful, or harmful or disgusted.	Student 1, pre-test: *Fear* Student 10, pre-test: *Avoidance* Student 12, pre-test: *Frightened* Student 20, pre-test: *Sick* Student 28, pre-test: *Tense* Student 35, pre-test: *Dread*
Indifference	Lack of interest, concern, or sympathy	Student 11, pre-test: *Normal* Student 15, pre-test: *No feelings* Student 18, pre-test: *Indifference* Student 28, post-test: *Relaxed*
Curiosity	Feeling about a strong desire to know or learn something	Student 1, pre-test: *Curiosity* Student 4, pre-test: *Interest*
Happiness	Feelings of positive emotions ranging from contentment to intense joy	Student 16, pre-test: *Happy* Student 27, pre-test: *Pleasant* Student 28, pre-test: *Happiness* Student 10, post-test: *Compassion* Student 14, post-test: *Good* Student 27, post-test: *Cute* Student 35, post-test: *Gratitude*

The answers to action towards reptiles (Q3) were assigned to five categories – very negative, negative, neutral, positive and very positive actions (**Table 3.2**). In the short answer about action towards reptiles, there were significance differences before and after the activity ($Z_{(1,57)}$= 6.56, p= 0.00). Most of the students in the pre-test refer that they were afraid or even tried to kill reptiles (**Fig. 3.1**). In post-test, positive actions, such as being helpful or curious were referred more frequently (**Fig. 3.1C**).

Table 3.2. Categories of analysis resulting from the literature review and free-floating reading of the answers of students to the question about actions towards reptiles (Q3), assignment criteria of each category and examples of their students' answers assigned to each category.

Criteria	Definition	Example
Very negative: kill or injure	Try to kill or hurt	Student 10, pre-test: *My first though is to kill it with a flip-flop or try to scare it to make it run away*
Negative: fear or dislike	Being afraid of something as likely to be dangerous, painful, or harmful	Student 2, pre-test: *I start to be afraid and sometimes I start to scream* Student 15, pre-test: *I leave the place where it is*
Neutral: indifference	Lack of interest, concern or sympathy	Student 21, pre-test: *I do nothing* Student 11, post-test: *I would stay normal*
Positive: curiosity	Desire to know or learn something.	Student 4, pre-test: *It depends of the reptile, sometimes I just look and sometimes I try to get closer* Student 24, pre-test: *I keep watching them because I want to know more about them* Student 26, pre-test: *I imagine how it is to be like a reptile* Student 6, post-test: *I would try to attract him with food to see its size*
Very positive: help	To offer services or resources to make it easier or possible for someone to do something	Student 1, pre-test: *I'd stay normal but if I see it (C. vaillantii) is in danger, I'd try to help it* Student 29, pre-test: *I try to understand what is happening to them (C. vaillantii), and I'd try to help it or call someone who can help it* Student 1, post-test: *I wish to have it in my hand! Lol, lol, lol!* Student 10, post-test: *I would talk to everybody not to hurt it* Student 14, post-test: *I would protect it and take care of it like a pet* Student 27, post-test: *I would try to catch it and find a better place for it.*

The multiple-choice question (Q4) about the importance of *C. vaillantii* also presented significant differences before and after the activity ($Z_{(1,58)}= 6.62$, p= 0.00). Students assigned higher importance to *C. vaillantii* in the post-test than in the pre-test (**Fig. 3.1D**). Low importance and no importance answers were only chosen in the pre-test (**Fig. 3.1D**).

Significant correlations were obtained between all pair of answers (**Table 3.3**), but it was stronger (>0.6) between Q1 – Q2 and Q1 – Q3.
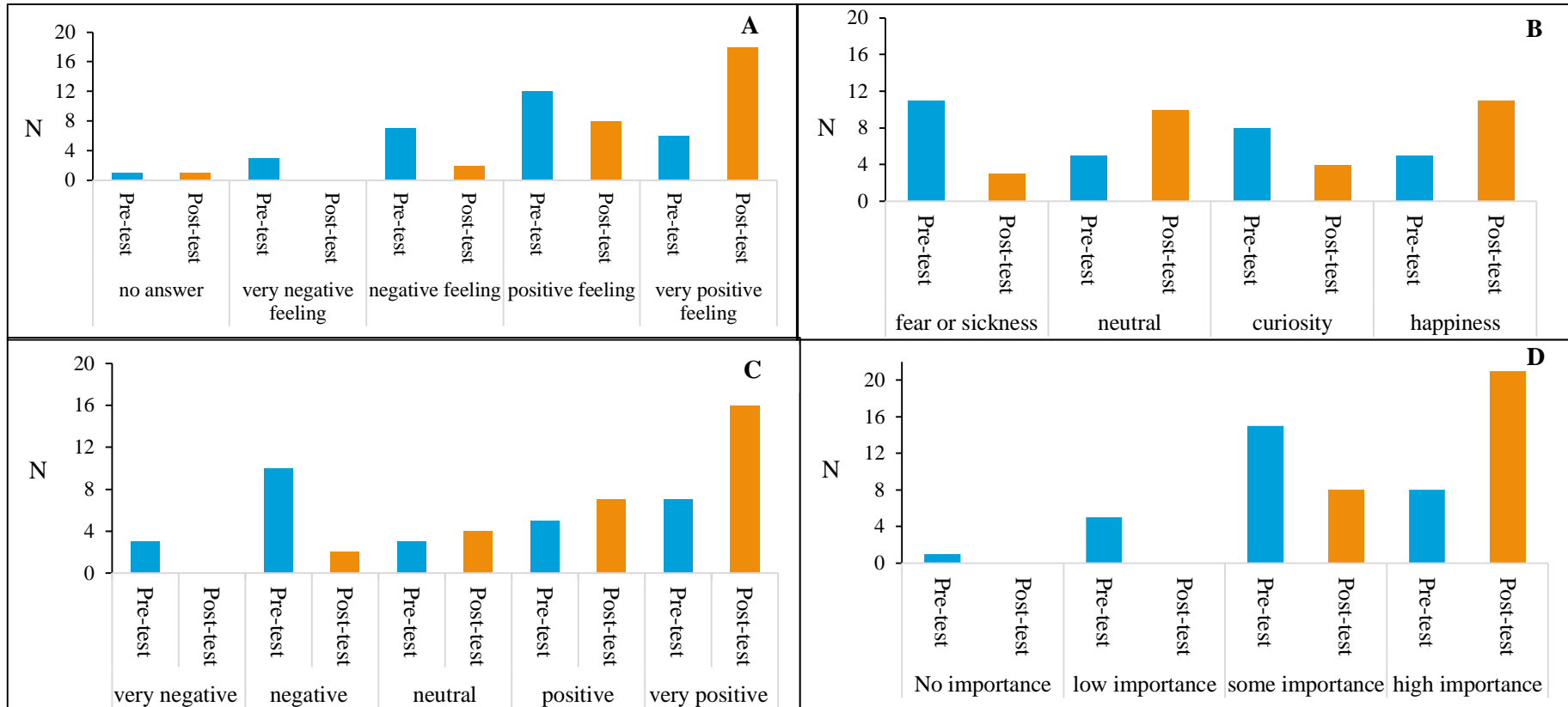
Figure 3.1. Frequency of the different categories of answers of students in the pre-test (in blue) and post-test (in orange). **A)** Results from the one-word question (Q1; N=29) and **B)** the Likert scale question (Q2; N=29) about what they feel towards reptiles or when they see one, respectively. **C)** Results from the question about their actions towards reptiles when they see them (Q3; N=29), and **D)** in the Likert scale question about the perceived importance of *Chioninia vaillantii* (Q4; N=29).

Table 3.3. Spearman's rank correlation tests between all the pairs of answers. Number of answers (N) to the different question (Q1 to Q4), and test (T), significance (p, *stands for p< 0.050) and correlation values (rs) are also given. The strongest correlations are marked in bold.

Variables	N	T	p	r_s
Q1 and Q2	57	6.06	0.00*	**0.63**
Q1 and Q3	56	6.66	0.00*	**0.67**
Q1 and Q4	57	2.90	0.01*	0.36
Q2 and Q3	57	5.30	0.00*	**0.58**
Q2 and Q4	58	3.64	0.00*	0.44
Q3 and Q4	57	5.17	0.00*	**0.57**

The students have decided that the total length of the video would be 14 min, and that it would include sections about the distribution and characteristics of the species in the introduction, its main threats and conservation actions in middle, and importance in the ecosystem in last. In addition, they decided they would approach those subjects by means of interviews, theatre pieces and films/ pictures of the lizard (video: https://www.youtube.com/watch?v=5Up6nSp59Uc). The video content analysis showed evidences supporting learning of students about the distinctive characteristics of the species (0:21 min), its ecology (0:52 min), as well as about its importance for the ecosystem (0:33 min), threats and conservation actions (1:31 min). In addition, direct contact between the students and the animal was observed in the video both in a natural (duration of this contact in the video: 2:00 min) and non-natural environment (duration of this contact in the video: 1:15 min). The frequency of general conservation motives enunciated by students in the video to protect *C. vaillantii* are presented in **Table 4**. The most frequent motive was related to endemicity, the fact of being a unique species from Cabo Verde and a unique subspecies of Fogo and Rombos (**Table 3.4.**).

Table 3.4. Frequency (N) of conservation motives enunciated by students in the video to protect *C. vaillantii*. Some examples from the transcriptions are also given.

Motive	N	Example
Endemicity	9	*"It's a lizard that only exists on Fogo Island"* *"It's ours"*
Rarity	5	*"This is a threatened lizard"* *"It is a rare species"*
Importance	5	*"Protects our food from pests"* *"Disperse seeds in the environment that lead to the birth of new plants"* *"Very important lizard".*
Beauty	4	*"Beautiful species"* *"It`s cute"*

3.4 Discussion

This study showed how PBL model could be decisive for promoting conservation. For adults, environment concepts and experiences from childhood might be decisive (Wells & Lekies, 2006). In our study, involving students in the production of a wildlife conservation film was important to develop positive perceptions and change attitudes towards reptiles the target species. These results are in line with previous studies that showed PBL approaches successfully enhancing the green chemistry and sustainability level of students and helped them to obtain a different perspective in terms of environmental awareness (Günter et al., 2017). We also have related the increased experience and knowledge with attitude improve, and increased of *C. vaillantii*'s perceived importance. PBL, in this case, a movie production, proved to be a good strategy to engage students who were afraid of reptiles to participate in the activity. Some previous studies have already shown that PBL is a good educational strategy to create emotional and cognitive engagement of student (Craft & Capraro, 2017; Sunderland, 2014; Wynn Sr et al., 2014). The use of the mobile technologies may have also contributed to these results. In fact, new technologies, like mobile technologies, have a huge potential for educational purposes (Sung et al., 2016) since they can increase students independence, engagement, and communication skills (Dunn et al., 2013). Besides, new technologies can promote group feedback and social processing by gathering and sharing information within the group (Roschelle et al., 2010). Moreover, students can use mobile phones to record work that they were proud, procedures in classes, and brainstorm sessions (Ferry, 2009). More importantly, mobile technology are easy to use and accessible to most (Ferry, 2009), thus facilitating the participation of students in our PBL activity. Moreover, PBL could have contributed to develop critical thinking towards their own perceptions and attitudes (Thomas, 2009). This was achieved by role-playing different judgments from the acquired experience and facing real and current problems of the species conservation by interviewing locals in the video. In similar studies, educating about an existing problem with a PBL approach improved the motivation of students to develop projects and increased awareness for sustainability (Aránguiz et al., 2020; Ozturk et al., 2008). In addition, working in teams allowed students criticizing constructively each other along the project. Working in teams is one of the main benefits of using PBL, and this have been described as one of the most important factors to improve attitudes (Faris, 2008). Another factor that could have triggered change in attitudes was the success to overcome the challenge proposed by us that lead to professional growth and the acquisition of constructive educational beliefs (Tsybulsky & Oz, 2019). In addition, the film was presented to the public at the school, and may have led students to feel more involved and proud of their work. This may have helped to change the perceptions about reptiles and, consequently, actions towards them and the perception of their importance. That factor sought to explain positive attitudes towards the project itself in a similar study (Tsybulsky & Oz, 2019).

In this work, students chose more frequently fear and curiosity feelings in the pre-test while in the post-test they chose more frequently happy and neutral feelings. The same happened in the Likert scale question, where students chose happier faces more frequently in the post-test than in the pre-test. Bearing in mind that these two questions are correlated, we can say that there was a change in the feelings towards reptiles from the pre-test to the post-test. Emotions can have a key role in raising environmental awareness of students (Robina-Ramírez et al., 2020). However, people possess a very strong and negative opinions and feelings about some of the most hated and feared animals (Ceríaco & Marques, 2013; Prokop & Tunnicliffe, 2008; Rinck & Becker, 2007). It is well known that reptiles are persecuted and feared (Ceriaco, 2012; Çiçek & Cumhuriyet, 2017). In fact, reptiles were a big threat for mammals in the past, which can be the basis for the predisposed ability to learn to fear snake-like organisms during our evolutionary history (Kawai & Koda, 2016; Öhman & Mineka, 2003), and for the existence of myths and folklores that passed throughout generations, even when snakes or poisonous reptiles are absent. Folklore and values are decisive to the effectiveness of conservation efforts of reptiles since negative perceptions, such as wrong ideas and negative values, are related with persecution and anti-conservation attitudes (Ceriaco, 2012). This is the case of Cabo Verdean myths and folklore as well (Vasconcelos et al. 2014), where no snakes or poisonous reptiles exist. In fact, some students revealed us unfounded fears about reptiles during the interviews (e.g., student 1: "people say that skinks swear on you while their tails are moving after being cut") and in the video. It is also important to highlight that the fact that the model species, as most skinks, has a snake-like appearance may activate the non-conscious cognitive response of averseness and fear more easily (Bennett-Levy & Marteau, 1984; Öhman, 2009). In other studies regarding other disliked animals, additional factors for the negative perceptions and attitudes towards reptiles were the lack of knowledge about these animals (Tingley et al., 2016). During the interviews, when asked for the reasons to fear skinks, students frequently mentioned that was because they were boneless like worms or larvae and thus disgusting or feared (e.g., student 9: "they are invertebrates (I don't know much about them"..."sometimes I fell scared and I don't like much when they get close"; "student 17: "reptiles are animals with an invertebrate body", "...sometimes I fell scared..."; student 30: "They are invertebrate animals/ insects..."). However, students had never touched reptiles to disprove that belief (personal communication of students), as direct contact with fauna is increasingly less frequent (Soga & Gaston, 2016). This possibly explains the higher incidence of negative feelings in the pre-test. However, those changed in the post-test probably due to the increase of empathy towards reptiles, and the increase of knowledge about these animals in terms of their morphology, ecology and role in the ecosystem, and their conservation status. These are working hypotheses that need further testing, however, we have seen in the third session how several students that were afraid to get close to the skink immediately approached it when others stated that they could feel bones in its tail (pers. obs.). It is possible that, when students realized that lizards had bones, are thus were more closely related to humans than to insects or worms, possibly empathy increased towards them, following the hypotheses of Miralles et al. (2019). As observed in contents of the produced video, and inferred based on the answers to

the questionnaires, students have learned during the activity that these animals are harmless for them and that are an important part of the ecosystem. The fact that students attributed more importance to *C. vaillantii* in the post-test than in the pre-test supports this. This may also explain why the frequency of answers related to curiosity decreased from pre to the post-test in the first question. But knowledge itself is known to be insufficient to reduce fear and persecution (Tomažič, 2011). While students were recording and producing the film, they also had physical and direct contact with these animals and probably created emotional bounds with the species. Physical contact is a very important factor for conservation of reptiles (Reynolds et al., 2018) and nature in general (Zhang et al., 2014). It would be interesting, in the future, to quantify how the contact with these animals can cause a change in the feelings and actions toward reptiles.

Apart from feelings, actions are also important in wildlife conservation (Pooley & o'Connor, 2000). With this activity, we could see an improvement in the possible actions of student if they encountered a reptile in the future. In the third question about actions of students towards reptiles, negative actions like kill, injury, and run were chosen significantly less frequently in the post-test than in the pre-test. Since the answers to this question were correlated with all the others, this result is expected. Correlations between feelings and actions was already reported in the literature: when people have positive feelings about an animal, their actions are more likely to be positive towards those animals (Miralles et al., 2019).

In future studies, we would like to further explore the relationship between the myths and the negative perceptions about these reptiles as previously approached by Vasconcelos et al. (2014), as well as other feared native animals, such as bats and spiders (Prokop & Tunnicliffe, 2008). It would be also important to explore the reasons that lead students to change their responses between tests and what factors students consider most important for the conservation of these animals in detail. For example, in the video, students have mentioned endemicity as the main reason to protect this species, so, it would be interesting to apply this methodology in a non-endemic species to test the relevance of endemicity for the results of this study. Besides the impacts on students, the movie produced through our PBL approach may have also impacted the feelings, perceptions and actions of other community members that watched or participated in the movie, or that discussed with the engaged students. However, evaluating such impacts is out of the scope of the present paper. For future studies, it would be interesting to study the impacts of the movie in the community. These findings would be important to promote education for sustainability while promoting awareness of local communities for conservation issues. If awareness actions embraced more people on Fogo Island and in Cabo Verde Archipelago, it will be easier to protect threatened species like *C. vaillantii* and other endemics. We hope that then, common people and stakeholders would potentially better receive investments in conservation.

3.5 ACKNOWLEDGEMENTS

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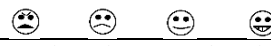
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3.7 SUPPLEMENTARY MATERIAL

Appendix S3.1. Questions (Q1 to Q4) used to evaluate attitudes by students in the Portuguese (original version) and English version (in italic).

Question	Type of question	Portuguese	English
Q1	One-word answer	Usa uma palavra para descreveres o que sentes quando vês um réptil.	*Use a word to describe what you feel when you see a reptile.*
Q2	Likert scale	Escolhe uma imagem em baixo que descreva o que sentes quando os vês: ☹ ☹ ☺ ☺	*Choose an image below that describes what you feel when you see them:* ☹ ☹ ☺ ☺
Q3	Open-question	Descreve o que fazes quando vês um réptil.	*Describe what you do when you see a reptile.*
Q4	Likert scale	De 1 (nada) a 4 (muito importante) assinala quão importante achas o lagarto chinel: 1) Nada importante 2) Pouco importante 3) Algo importante 4) Muito importante	*From 1 (nothing) to 4 (very important) indicate how important you think the Vaillant's lizard is:* 1) *Not important* 2) *A bit important* 3) *Somewhat importan* 4) *Very important*

Appendix 3.2. Transcription of the video contents in Portuguese (original version) and its English translation (in italic).

00:10min
Somos estudantes de Ponta Verde, estamos a participar num projecto de conservação do lagarto de Vaillant.
00:18min
Este é que é o lagarto maior da ilha do Fogo. Este tem a pálpebra preta e o ouvido amarelo. Ele é vivíparo, ou seja, não põe ovos.
00:30min
Saiu tudo lá do buraco.
00:31min
Ali está aquela orelha amarela, aquelas duas, três riscas nas costas.
00:44min
Tu és grande!
00:52min
Ele é espertinho!
00:56min
O lagarto de Vaillant é uma lagartixa que existe só na ilha do Fogo, na parte norte, porque só ali que ele tem condições de viver.
Como ele está a passar por muitos perigos de desaparecer, nós estamos a participar neste projecto para ajudar a comunidade a conhecê-lo melhor e a protegê-lo.
01:21min
É incrível! Ele está ali, ali!
01:24min
Ei!
01:26min
Ele vive em lugares frios, entre pedras. Ele é omnívoro, ou seja, ele come um pouco de tudo.
01:33min
– Talvez ele venha à procura. Achou o amigo dele. Ele está a olhar o amigo dele!
– É mas é o seu namorado…
– (risos)
– Olha lá debaixo, ele está à tua frente!
– Ya moça!
– Olha lá em cima, Nady!
– Ughhh!
– Olha lá! Ali, ali, ali, ali, ali!
– Quê?
– Vê ali!
– Segue o meu dedo...
– Ah! OK. Ah, ele já foi para lá...
– Isto já chega, deve chegar, não?
– Stop. Está bom. Eles são bem-educados.
02:12min
– Senhora, já, já costuma ver muitos lagartos de Vaillant, não é?
– Sim, já vi sim.
– Pronto. Então é assim: no momento em que chega à sua casa, no momento em que está a chegar, um entra na sua casa. Qual é a primeira reacção que tem?
– A minha reacção é matar e tirá-lo de dentro de casa.
– Porque é que o mataria?
– Porque o lagarto de Vaillant é um bicho que não deve estar dentro de casa.

– A senhora acha que é um bicho tipo sujo...

– Sujo (abanando com a cabeça)!

– Nojento, não é?

– (diz que sim abanando com a cabeça).

– Acha que não tem nenhuma importância para o meio ambiente, não é?

– Sim, ele não pode estar ali. É para o matar ou tem que estar no buraco dele quietinho...

– Obrigada pelo seu tempo, você foi muito prestável.

03:41min

– Boa tarde. É assim que vocês se comportam?

– Sim!!!

– Então, tudo bem?

– Sim

– A família?

– Estás atrasada!

– Desculpe professora.

– Atrasada!

– Tenho aqui uma pequena surpresa para vocês!

– (gritos)

– Calma! É só, é só um lagarto!

– (gritos)

– Adê, é só um lagarto! Adê, Adê, Adê É só um lagarto!

– Adê, Adê, ele não te vai fazer nada! É só um lagarto, viste? Ele fez–te alguma coisa, ou não Deyse? É só um lagarto! Este é um lagarto que só existe aqui na ilha do Fogo Adê. Tu tens que o proteger o que é nosso. Não se pode estar assim a matar lagartos à toa. Gostarias que alguém te matasse? Este é um lagarto em extinção e que existe só na ilha do Fogo, ou não Deyse?

– Sim, e é importante! É importante porque, para além de existir só aqui, é uma espécie rara e também nos protege das pragas dos nossos alimentos. Portanto é muito importante e bonita também! É um animal como todos os outros animais.

– Tem características específicas só deste lagarto. Olha, olha! Vamos tocar só para experimentares. Só tocar. Olha. Ele fez alguma coisa?

– Não

– Então porquê estás com medo Adélia?

– Meninos, é para matá-lo?

– NÃO!!!!!!!!!!!!!

– Ele é fofo, não mata, não!

– Ui! Porquê?

05:26min

– Estamos a fazer um trabalho sobre a lagartixa e queremos saber a sua opinião sobre ela. Não tem problema?

– OK

– OK. Primeira pergunta: gostaria que nos dissesse o que é que sente assim que a vê uma lagartixa? Podem ser só duas palavras ou três.

– Eu sinto–me normal.

– Normal, nada de nojo de certeza? Nada?

– Nada.

– OK. O que é que faz assim que a vê? O teu primeiro instinto é matá-la ou dar–lhe com uma chinelada...?

– Não, não faço nada.

– Não a mata?

– Não a mato.

– Óptimo.

– OK. E acha que elas têm alguma importância para o meio ambiente, ou tipo assim: "elas não têm importância nenhuma, não servem para nada, deixam-nas para lá…."

– Tem importância, sim!

– Ao certo ...ou não sabe?

– Não sei qual a importância delas, mas têm importância sim.

– Obrigada.

– Obrigada.

06:23min

– E hoje vamos falar com a Senhora Lisa, uma especialista em lagartixas. Lisa, por favor. Obrigada pela sua presença.

– De nada.

– Lisa, pode explicar-nos mais sobre esse tipo de lagartixa?

– Tipo, essas lagartixas encontram–se mais naqueles buracos, naquelas casas antigas. Então, com a modernização, todo o mundo está a construir casa mais modernas e mais novas, então quando têm que construí–las naqueles terrenos que têm casas mais velhas, eles querem construir casas novas aí. Quando eles vêm, querem demolir aquelas casas velhas para fazer as novas casas deles. E assim, acabam por destruir, derrubar esses buracos onde as lagartixas vivem. E também, mais ainda, eles querem fazer novas estradas, alargar estradas e assim elas poderão sofrer algum atropelamento, derrubar as casas delas e acabar por destruir totalmente os lugares onde elas moram.

– E o que é que quer dizer sobre, por exemplo, para preservar esse tipo de espécie daqui?

– Para preservá-lo? Será que é necessária tanta quantidade de casas? Há quem tenha duas ou três casas na mesma localidade, ou uma na vila de São Jorge e outra lá em São Filipe. Qual é a necessidade disso? E para quê tantas estradas, tão largas assim? Vai acabar por matá-las... então a melhor coisa a fazer é preservá-las do que estar a demolir todas as casas delas e do seus filhos também para tentar protegê–las. Temos de protegê-las também dos gatos, desses animais que tentam comê-las, os seus filhos, os seus ovos e tudo mais.

– Então qual é a importância desta espécie?

– Ela tem muita importância, ela é uma espécie que ajuda na decomposição de muitas, muitas coisas no meio ambiente. Ainda mais, elas dispersam um monte de tipo de sementes no meio ambiente que levam ao nascimento de novas plantas. Elas são muito importantes, elas têm muita importância.

– Bom, qual é que é a mensagem que quer deixar para a população preservar essas lagartixas?

– Protejamo-la porque é uma espécie bonita que existe só aqui na ilha do Fogo. Ela é uma espécie rara mesmo. Existe só aqui. Gente, devemos protegê-la, ela é nossa!

09:02min

– Felisberta!

– Oi, mãe!

– O que é que tu estás a fazer a brincar com esse lixo aí?

– Olha, queima e tira–me isso da porta de casa. Estão aqui os fósforos, queima isso. Tira–me isso da porta que eu não gosto disto.

– Não vou queimar nada do que está ali!

– Filha, acredita que a mãe é grande e tem que ir limpar a casa.

– Não vou queimar.

– És a bebé da mamã (beija–a). Tu és queridinha, fofura… Depois dou–te algo em casa. Faz o que te digo…

– OK!

– Queima lá isso! Já venho (beija–a). Xau!

09:44s

– Ahhhhhhhh! Não!!! Ahhhhhhhh! Não!!! Tu és doida?! Ali é onde os lagartos moram! E tu estás estás a fazer–lhes mal (tenta abraçá–la) Ah! Estás molhada, fica aí!

– Mas a mamã mandou!

– Mas não podes! Sabes porquê? Ali perto vive um lagarto que só existe na ilha do Fogo, minha irmãzinha. Não podes vir dar cabo dele por nada deste mundo. Olha lá, é sério filha: ali perto estão uns lagartos que são super importantes, entendes porquê?

10:46min

Ele é tão fofo…

12:17min

Nós protegemos aquilo que é nosso para não o perdermos.

14:04min

– Felisberta! Não sei o teu nome… é Felisberta que tenho que te chamar? Desculpa! (risos).

00:10min

We are students from Ponta Verde, we are participating in a conservation project about the Vaillant's lizard.

00:18s

This is the largest lizard on the Fogo Island. It has a black eyelid and a yellow ear. It's viviparous, so, it does not lay eggs.

00:30min

It all came out of the hole.

00:31 min

There is that yellow ear, those two, three stripes on the back.

00:44 min

You're big!

00:52min

It's smart!

00:56min

The Vaillant's lizard is a lizard that exists only on the Fogo Island, in the northern part, because it's the only place that have the conditions to live.
As it's going through many dangers to disappear, we are participating in this project to help the community to know it better and protect it.

01:21min

It's incredible! It's over there, over there!

01:24min

Hey!

01:26min

It lives in cold places, among rocks. It's omnivorous, meaning it eats a little bit of everything.

01:33min

– Maybe it comes looking for something. It found its friend. It's looking at his friend!
– It's its boyfriend instead...
– (laughs)
– Look down there, it's in front of you!
– Ya girl!
– Look up there, Nady!
– Ughhh!
– Look there! There, there, there, there, there!
– What?
– Look over there!
– Follow my finger ...
– Ah! OK. Ah, it already went there ...
– This is enough, it should be enough, isn't it?

– *Stop. Is good. They are well–behaved.*
02:12min
– *Mrs, you usually see many Vaillant's lizards, right?*
– *Yes, I've seen it already, indeed.*
– *Ok. So, the moment you arrive at your home, in the moment you arrive, one enters your house. What is your first reaction?*
– *My reaction is to kill it and get it out of the house.*
– *Why would you kill it?*
– *Because Vaillant's lizard is an animal that should not be inside the house.*
– *Mrs, you think it's a dirty animal ...*
– *Dirty (shaking his head)!*
– *Disgusting, isn't it?*
– *(says yes, shaking his head).*
– *You think it doesn't matter at all to the environment, isn't it?*
– *Yes, it can't be there. It's to kill it or it has to be in its hole quietly...*
– *Thank you for your time, you were very helpful.*
03:41min
– *Good afternoon. Is that how you behave?*
– *Yes!!!*
– *So, all OK?*
– *Yes*
– *Your family?*
– *You're late!*
– *Sorry, ma'am.*
– *Late!*
– *I have a little surprise here for you!*
– *(screams)*
– *Calm down! It's just, it's just a lizard!*
– *(screams)*
– *Adê, it's just a lizard! Adê, Adê, Adê It's just a lizard!*
– *Adê, Adê, it won't do anything to you! It's just a lizard, ok? Did it hurt you, or not Deyse? It's just a lizard! This is a lizard that only exists here on Fogo Island, Adê. You have to protect what is ours. You can't be killing lizards for nothing. Would you like someone to kill you? This is a threatened lizard that exists only on the island of Fogo, or not Deyse?*
– *Yes, and it's important! It's important because, besides existing only here, it is a rare species and also protects us from the pests in our food. Therefore, it is very important and beautiful too! It's an animal like all other animals.*
– *It has specific characteristics of this lizard. Look, look! Let's touch it just to see. Just touch it. Look. Did it do anything?*
– *No*
– *So, why are you afraid Adélia?*
– *People, should I kill it?*
– *NO!!!!!!!!!!!!*
– *He's cute, don´t kill it, no!*
– *Ui! Why?*
05:26min
– *We are doing a work about a skink and we want to know your opinion about it. No problem?*
– *OK*
– *OK. First question: would you like to tell me what do you feel as soon as you see a skink? It can be just two words or three.*
– *I feel normal.*
– *Normal, no disgust for sure? Anything?*

– Nothing.
– OK. What do you do as soon as you see it? Your first instinct is to kill it or strike it with a slipper…?
– No, I do nothing.
– You don't kill it?
– I don´t.
– Great.
– OK. And do you think they have any importance for the environment, or something like this: "they have no importance at all, they are useless, leave it there…"
– Yes, they do have importance!
– Specifically… or you don't know?
– I don't know the importance they have, but they have importance, indeed.
– Thank you.
– Thank you.

06:23min
– And today we will talk with Mrs Lisa, a specialist in skinks. Lisa, please. Thank you for your presence.
– You're welcome.
– Lisa, can you explain us more about this kind of skink?
– Ok, these skinks are found in those holes, in those old houses. So, with modernization, everybody is building more modern and newer houses, therefore when they have to build on lands with older houses they want to build new houses there. When they come, they want to destroy these old houses to build their new houses. In this way, they end up destroying, knocking down those holes where the skinks live. In addition, even more, they want to make new roads, to widen the roads, and so the skinks can be road killed, destroy its houses and end up totally destroying the places where they live.
– And what do you want to say about ways to protect this kind of species here, for example?
– To protect it? Are that many houses needed? There are people that have two or three houses in the same locality, or one in the village of São Jorge and another in São Filipe. What's the need for this? And, why so many roads, so wide like that? It will eventually kill them … then the best thing to do is to protect them rather than to demolish all their homes and their children, and to try to protect them as well. We shall protect them also from cats, of those animals that try to eat them, their children, their eggs and everything.
– So, why is this species important?
– It is of much importance, it's a species that helps in the decomposition of many, many things in the environment. Furthermore, they disperse a lot of types of seeds in the environment that lead to the birth of new plants. They are very important; they are of much importance.
– Well, what is the message you want to send to the population to protect these skinks?
– We must protect it because it is a beautiful species, which exists only here on Fogo Island. It's a rare species indeed. There is only here. People, we must protect it, it is ours!

09:02min
– Felisberta!
– Hi mom!
– What are you doing there playing with that trash?
– Look, burn it and get it out of my door. Here are the matches, burn that. Get it out of the door. I don't like it.
– I will not burn it!
– Daughter, believe in me that I'm a grownup and I have to go clean the house.
– I will not burn it.
– You're mommy's baby (kissing her). You are a little darling, sweetie… Then I'll give you something at home. Do what I tell you…
– OK!

– Burn it, then! I will be right back (kissing her). Bye!

09:44min

– Ahhhhhhhh! No!!! Ahhhhhhhh! No!!! Are you crazy?! That's where the lizards live! And you're harming them (tries to hug her) Ah! You're soaked, stay there!

– But mom said so!

– But you can't! Do you know why? A lizard that only exists on Fogo Island lives nearby, my little sister. You cannot harm it, for nothing in this world. Look, this is serious daughter: there are some super important lizards nearby. Do you understand the reason?

10:46min

It's so cute...

12:17min

We protect what is ours so we don't lose it.

14:04min

– Felisberta! I don't know your name… it's Felisberta that I have to call you? Sorry! (laughs).

4. GENERAL CONCLUSIONS

As the National Directorate of the Environment of Cabo Verde supported this study, the ultimate goal of this master thesis was to contribute to the conservation of an endemic and Endangered skink of Cabo Verde, *Chioninia vaillantii*. This work brought new data on the ecophysiology and thermobiology of reptiles, and on the behaviour of pregnant viviparous females, even though there is still much to explore. Knowledge about the physiological requirements of the species will potentially better explain its distribution and microhabitat selection. This work also tested a project-based learning (PBL) activity in order to increase empathy with animals that are seen with hatred by the local human populations. It is also important to refer that this work promoted capacity building by training technicians from a local ONG during one month, enhancing their lab and field herpetological methodologies and knowledge about *C. vaillantii* and other reptile species. The outputs of this thesis, and the way they are interconnected, are resumed in **Fig. 4.1**.
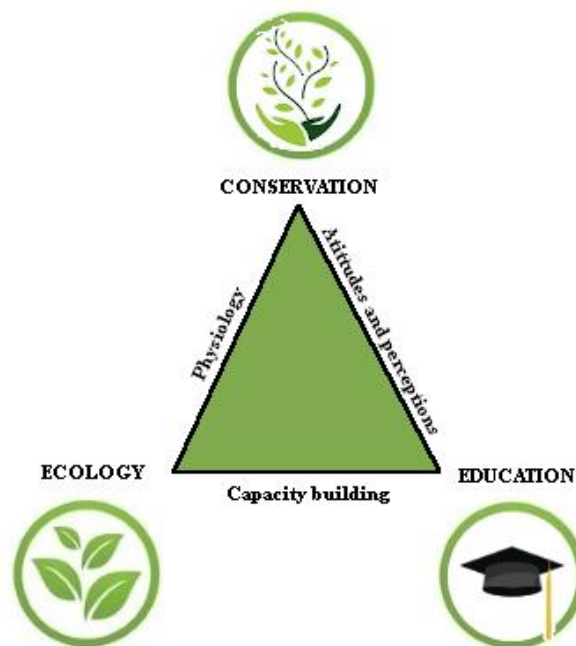

Figure 4.1. Main study themes approached in this master thesis and their connections.

Little was known about the ecology of this species before this study (Vasconcelos, 2013). Knowledge about its basic thermal and hydric ecology that I have recovered for the first time is important to enhance conservation actions (Whittaker et al., 2008). Additionally, by integrating students into a PBL activity, bonds of empathy could be created between them and reptiles, notably with *C. vaillantii*, which may facilitate conservation actions in the future. Despite, the numerous campaigns to protect reptiles in Cabo Verde (Marco et al., 2011; Monzón-Argüello et al., 2010), the majority of these campaigns focus on marine reptiles and almost none on terrestrial

reptiles. I hope that this work will serve as a basis for more awareness campaigns for the terrestrial reptiles.

The main threats to this species are habitat disturbance, natural disasters, introduced species, and climate change (Vasconcelos, 2013). As Cabo Verde temperatures are raising (Cropper & Hanna, 2014), the diurnal skink *C. vaillantii* will probably suffer more than *C. delalandii* or other endemic nocturnal species present on Rombos, Fogo and Santiago according to our results, as it selected lower temperatures than *C. delalandii* but higher temperatures when water was unavailable in comparison to when it was unavailable. Thermoregulation is important for reptiles, because they need to reach optimal performances as ectotherms (Huey & Slatkin, 1976). Therefore, if temperatures rise, it could have implications for sex determination, metabolic rates, and to the bioavailability of water, what could have serious and irreversible effects on these organisms (Bickford et al., 2010). Knowing the thermal and hydric preferences of *C. vaillantii*, it is easy to predict its distribution will shrink, since this species is restricted to the more humid and/ or fresher areas of Fogo and Santiago islands (Vasconcelos et al., 2013).

Water availability is also an important factor for lizards (Lorenzon et al., 1999). Understanding how the species behaves when water is unavailable is also important to predict future distribution patterns. In Cabo Verde, there have always been long drought periods and a low precipitation rates (Correia, 1998). Due to CC, the environment is becoming warmer worldwide, which leads to high evaporation rates, that increases the intensity and duration of drought and decreases precipitation rates (Trenberth, 2011). Cabo Verde is no exception, with the intensification of aridification (Lacerda et al., 2015). While some species may know how to compensate lack of water with behaviour thermoregulating differently when water is unavailable, others might suffer when water is restricted. The behaviour of *C. vaillantii* revealed that this species might suffer in the future with CC effects. When exposed to controlled low humidity conditions, *C. vaillantii* does not seem to suffer in these conditions comparatively to *Chioninia delalandii* due to a higher surface/ volume ratio might explain the water loss by both species. However, in conditions closer to reality, as in the test in terrariums, *C. vaillantii* loses more body mass percentage when there is lack of water than *C. delalandii*. For the conservation of this Endangered species is important to know that hydric and thermal ecology are interacting, and are important to predict distribution patterns of *C. vaillantii* in a near future.

We need to pay special attention to *C. vaillantii* as by being largest extant Cabo Verdean skink is more prone to go extinct (Slavenko et al., 2016). In addition, it is viviparous (Metallinou et al., 2016), so a low reproductive output is expected. This skink species can be used as model for conservation of endemic reptiles in Cabo Verde, because, with the predicted increasing temperatures, some lizards might be similarly affected. Since pregnant females preferred lower temperatures, actions for conservation are needed to guarantee the availability of selected microhabitats. Some of these actions could be related to habitat management, by maintaining the old stonewalls and the native vegetation that can help to maintain more humidity and cooler

temperatures. In addition, it would be important to monitor the reproductive output of the population of this species. Another action is to aware and teach the landowners to preserve these structures. Is crucial for the species to propose policies and regulations to the government that maintain, encourage and support the protection of the native populations of this species and its habitat. Thus, as the actual predicted distribution of this species on Fogo is entirely outside the existing protected area (Vasconcelos et al., 2012), new protected areas are recommended to encompass it. On Fogo Island, the expansion of the Natural Park, which lies in the centre of the island. to the north-east until the coast is needed. In addition, two new protected areas were recommended in the east and northwest of the island, around the areas where we found the most dense populations of *C. vaillantii* and collected individuals for this study (Vasconcelos et al., 2012). On Santiago Island, a new protected area at inland mountainous area is recommended or a corridor connecting the two Natural Parks (Vasconcelos et al., 2012). On Rombos, despite being an Integral Reserve, little conservation managing effort has been made. Therefore, it is important to research the impact of invasive species like mice on *C. vaillantii*. Mice are probably predating on skinks, because *C. vaillantii* individuals are much more aggressive and larger than those found on Fogo Island, and *C. delalandii* individuals have very low densities (pers. observ.). Therefore, conservative actions are urgently needed.

Another of the important threats to *C. vaillantii* is persecution (Vasconcelos et al., 2013). Education and science communication are hence important to raise awareness about its conservation status and threats (Bickford et al., 2012). The project-based-learning activity we performed, a movie production about *C. vaillantii*, proved to be an impacting activity. Students, by learning by themselves probably developed critical and empathic thoughts about the species. As both humans and the skink are viviparous, students most likely created some emotional link and increased their will to protect this skink species. The more human characteristics a species has, the easier it is to empathize with it (Miralles et al., 2019). Moreover, since this species is endemic of Fogo and Santiago islands, students probably felt a greater desire to conserve this species, as it is unique and shares their homeland with them. By changing their perception about *C. vaillantii*, students will probably, in the future, support conservation more easily and be more prone to get involved in conservation actions, such as the ones proposed below and resumed in **Fig. 4.2**:

1) Management of agricultural development to ensure habitat and microhabitat protection.

2) Interdiction to kill, disturb, or damage animals or their habitat.

3) Implementation of new protected areas that encompass this species on Fogo and Santiago.

4) Education of the local community to raise awareness about the species.

5) Research on the population status and natural history of this species, and on the impacts of other threats.

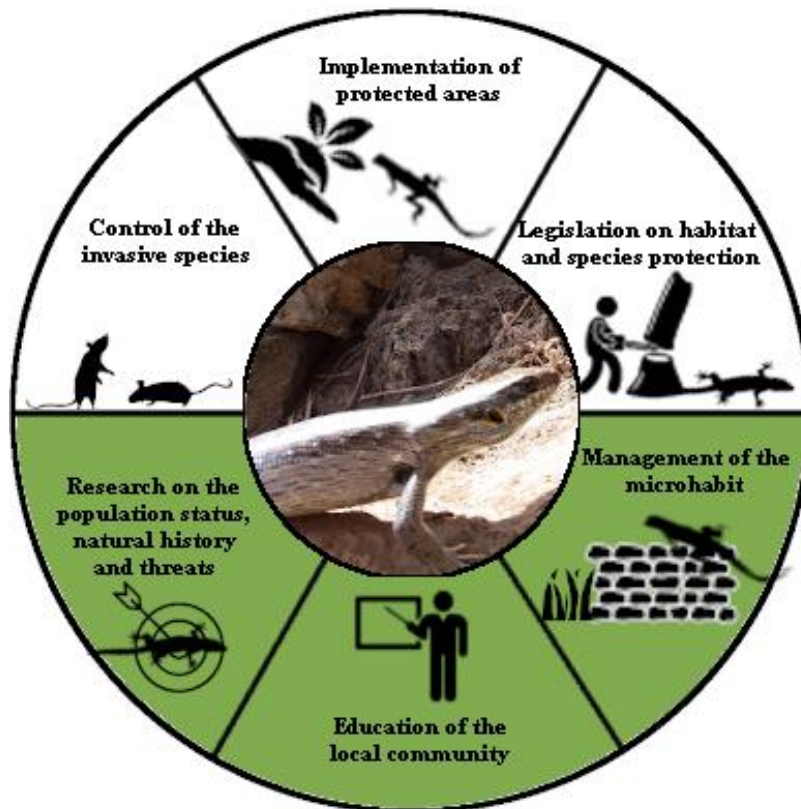6) Control and eradicate the invasive species like mice on Rombos and *Agama* on Santiago.

Figure 4.2. Conservative actions proposed to protect *Chioninia vaillantii*. Filled in green are the conservation actions that I already approached with this master thesis. Filled in white are proposals that needed to be approached in future studies.

4.1 LIMITATIONS AND FUTURE RESEARCH

During the course of this work, some limitations were met, although none influenced significantly the results. Nevertheless, these setbacks, if overcome could have complemented our findings or improved the statistical power of some tests.

The time and number of terraria we had to perform the thermoregulation experiment and the water loss tests in the lab was limited due to financial and logistic constrains, limiting the number of individuals tested. In the future, it would be important to try to include more pregnant females as well as control animals (non-pregnant), and repeat the test with at least 10 pregnant individuals. It would be interesting to repeat the Evaporative Water Loss test with a duration of 12 hours, as already applied in other studies (Carretero et al., 2016; Sannolo et al., 2018).

The study also focused on the short term effects of dehydration, which may not correspond to the reality experienced by animals. It would be important to study how these animals cope with droughts, as these are frequent in Cabo Verde, and will probably increase in frequency in a near future (Lacerda et al., 2015). It would be important to have more frequent control in the test of

the use of the space because the animals vary the position several times during one hour. Thus, shortening this timing could reduce the randomness of the position in which the animals are.

The study was done with isolated individuals although this species is known to share microhabitat with other individuals and other species (pers. observ.). Studies with intraspecific interaction have already been conducted in other Cabo Verde islands with other endemic species (Pereira et al., 2019) and showed that social factors are important. Individuals of the same sex, different ages or different sizes had lower aggregation frequencies than individuals with different sex, same ages or same size (Pereira et al., 2019). It would be interesting to study the interspecific interactions as to test if those could affect thermal and/ or hydric preferences.

The results of the lab may not accurately reflect tests in the natural environment. Therefore, it is important to carry out further studies *in situ*, for example: sampling the temperatures of the animals in different microhabitats or sampling the temperature of the microhabitat selected by the individuals.

In the PBL activity, more students could have been involved in the movie production, but due to time and logistic constrains, the number of students that participated was limited to the minimal number to enable the good performance of the statistical tests. In the future, with more time, we aim to incorporate a more diverse group of students, which would allow us to make, for instances, comparisons of the results between age classes and sexes as well. In addition, the impact of this activity was on a small scale (only in one school in one island). As referred by Vasconcelos (2013), more education is necessary to promote conservation towards *C. vaillantii*. To do so, a survey englobing all the Cabo Verdean community should be made to assess this question at a broader scale. I would like to implement this activity in other high schools on Fogo Island and even on Santiago Island, possibly targeting also younger crowds, including children, as the use of cell phones at earlier ages is increasing (Divan et al., 2012). Finally, we also do not know how the activity we carried out affected the local community that saw the film, and if that activity changed their inclination to support the conservation of reptiles in general and this species in particular. In the future, new studies should be designed to evaluate if their perception towards this species has changed and if this has proven to be successful and had significant results for species conservation.

Reptiles can be important seeds dispersers despite receiving much less attention than insects, birds and mammals (Olesen & Valido, 2003). Until now, 470 lizard species were identified to consume fleshy fruits (Valido & Olesen, 2019), and 78 of them were skink species, representing the family that eats more fruits of the fruit-eating lizards (Valido & Olesen, 2019). Interestingly, 62.4% of those 470 reptiles, inhabit islands (Valido & Olesen, 2019). Reptiles, especially in oceanic islands, have been shown as good seed dispersers (Heleno et al., 2013; Olesen & Valido, 2003; Valido & Nogales, 1994). Other studies, also pointed lizards as important pollinators (Olesen & Valido, 2003), even on oceanic islands (Hervías-Parejo et al., 2020; Ortega-Olivencia et al., 2012). Revealing the main ecological roles played by reptiles is important for the

development of conservation plans by governmental authorities. In future studies, it would be interesting identified plants, arthropods, and vertebrates consumed by *C. vaillantii* using metabarcoding of faecal pellets to grasp its ecological role and important links with endemic vertebrates, invertebrates and plants. If people perceive the species as useful, as, for instance, plant dispersers or predators of invertebrates that damage agricultural crops, they are more likely to protect it (García & Vasconcelos, 2017; Tessema et al., 2010). In addition, if we know what this species eats, we can protect the prey/ plants most important for their survival, similarly to what was done to the Endangered and endemic giant wall gecko, *Tarentola gigas* (Pinho et al., 2018).

More data about the behaviour ecology of this species is needed for improved conservation planning (Greggor et al., 2016; Merrick & Koprowski, 2017; Sutherland, 1998). In future studies, it would be interesting, to research how each of the threats (climate change, habitat disturbance, invasive species, geological activity, and persecution) affect the survival, reproduction, mating system, and fitness of *C. vaillantii*.

Studies about microhabitat selection are also necessary since this species seems to prefer agricultural land with vegetation cover and stonewalls (Vasconcelos, 2013), but these characteristics are absent on Cima Islet were the species also occurs (pers. observ.). This led us to infer that other characteristic are present on the islet to sustain its existence and that more research is needed to understand the ecological differences among populations from different sites. Also, it would be important to redo the areas of potential distribution, using this time mechanistic models of ecological niche modelling based on our physiological data and predictions of climate variables, as soon as they are available in a resolution compatible with the scale of the islands.

It is necessary to perform more physiological studies of the species to improve these models with individuals from Santiago Island and Cima Islet as well. Finally, it is also necessary to monitor the variation of the distribution area and of the number of mature individuals to establish whether the population is stable, or if it is growing or, on the contrary, if it continues to decline (Vasconcelos, 2013).

In conclusion, the first steps towards the conservation ecology of this species were taken. However, the threats are still present and it is necessary to know more at various levels so that future conservation actions may have the maximum benefit for the unique Valliant's skink.

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5. Supplementary Material

Appendix I. Oral communications in congresses

5.1. TiBE 2019 (Trends in Biodiversity and Evolution): Biodiversity, Ecology and Evolution in Mediterranean Ecosystems. Vairão, Porto.

Hot is worst if dry: a ecophysiological message from Cabo Verde lizards

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Abstract

Climate change (CC) scenarios forecast intense environmental shifts in the Mediterranean Basin biodiversity hotspot, and sedentary ectotherms are expected be the most affected organisms. We expected to provide clues on how species inhabiting milder climates will respond to CC analysing the physiological responses of reptiles inhabiting the most arid and warmest areas in this region.

Cabo Verde Archipelago presents high numbers of endemics, some threatened by CC. On Fogo Island, two endemic viviparous skinks have contrasting sizes and distributions. While *Chioninia vaillantii* is larger and restricted to cooler/humid areas in the northeast, *Chioninia delalandii* is smaller and distributed across the island, even in hotter/more arid areas. This suggests that the first is more restricted in its thermal/hydric ecophysiology than the second, explaining its distribution. Additionally, pregnant females are expected to be more sensitive to CC. We experimentally tested both hypotheses by measuring evaporative water loss (EWL) rates, and determining preferred temperatures (Tpref) and space use of 10 individuals of both species, with/without water available. The species differed in EWL due to surface/volume ratio differences. *C. delalandii* kept higher Tpref and was more frequently found in the hot part of the terrarium than *C. vaillantii*. As expected, lack of water affected Tpref, and all pregnant females selected lower Tpref than conspecific males and non-pregnant females.

This evidence confirms recent findings, suggesting that water ecology modulates thermoregulation in ectotherms, and that aridification will intensify CC effects. Overall, Cabo Verde lizards may be useful models of the Mediterranean Basin ectotherms for Conservation Biology.

5.2 #SciComPt2020 Online Congress

Shooting skinks for good: producing a film improves attitudes towards a threatened species

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Abstract

Education for Sustainable Development is important for children to develop positive values and attitudes towards nature conservation. Social factors like social media, folklore and beliefs, are also important in wild-life human conflicts but are barely considered. This can lead to negative attitudes and influence knowledge and perception of students towards animals and their conservation. Despite its importance in food chains and ecossistem services, reptiles are often negatively influenced by folkore and beliefs, resulting in fear and persecution. In Cabo Verde, reptiles are threatened by many factors including persecution. *Chioninia vaillantii* is a skink species that is classified as Endangered by IUCN red list feared by many. This species is endemic on Fogo and Santiago islands, in the south of Cabo Verde and is only found in higher altitudes in colder and more humid areas.

With this work, we proposed a project based learning activity to high-school students to improve their perceptions,knowledge and attitudes towardsreptiles in general and *C. vaillantii* in particular. The students were asked to write a script, shoot and produce p a short film that could improve the knowledge and attitudes of their community towards this endemic species. This movie was then publically presented to the community in a public event. To evaluate the impact of the activity, students were asked to fill in two questionnaires, before and after the activity. Our results showed differences in knowledge of students about the reptiles and attitudes towards *C. vaillantii* between and after the activity, supporting that it contributed to changes in the students. This fidings suggest that movie production may facilitate the education for sustainability, contributing to foster positive public attitudes towards species conservation.

5.3 SCE:NE — Science Communication Eclosion: Narrative Edition

Shooting skinks for good: producing a film improves attitudes towards a threatened species

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Abstract

Despite the importance of reptiles in food chains and ecosystem services, they are often negatively influenced by folklore and beliefs, resulting in fear and persecution. In this scenario, Education for Sustainable Development (ESD) may contribute for children to develop positive values and attitudes (feelings and actions) towards nature and, in particular, towards reptile conservation. Some studies showed that watching wildlife videos improves attitudes of people towards wildlife. However, few information is available on the impact of engaging people in movie production in their attitudes and perceptions.

Here we propose a project-based learning outreach activity implemented with Cabo Verdean high-school students and planned to improve their perceptions and attitudes towards reptiles in general, and the Endangered endemic skink *Chioninia vaillantii* in particular. We asked students to write a script, shoot and produce a short film that could improve the knowledge and attitudes of their community towards this endemic species. This movie was then presented to the community in a public event. To evaluate the impact of the activity, students were asked to fill in two questionnaires, before and after the activity.

Our results showed significant increase of positive feelings of students about the reptiles, and increased perception of their importance, and of positive attitudes towards *C. vaillantii* from pre to post test. These findings suggest that movie production may facilitate ESD, contributing to foster positive public attitudes towards species conservation by increasing emotional connections.

Keywords: Fogo Island; project-based learning; school; Vaillant's skink