

UNIVERSIDADE DE LISBOA  
FACULDADE DE CIÊNCIAS  
DEPARTAMENTO DE BIOLOGIA



**Eurasian otter (*Lutra lutra*) temporal and spatial ecology in  
Mediterranean streams**

Guilherme Melo Madeira

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Dissertação orientada por:  
Professor Doutor Luís Miguel Rosalino  
Professora Doutora Margarida Santos-Reis



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## Resumo

As alterações climáticas são um dos grandes fatores de ameaça para a biodiversidade a nível global, pois induzem alterações ao nível da estrutura e funcionamento das comunidades. Estas alterações podem levar a um aumento das temperaturas e a um decréscimo dos períodos de pluviosidade, o que pode originar a uma intensificação dos períodos de seca. Apesar de puderem afetar as comunidades de todos os ambientes terrestres, o nível de impacto pode variar grandemente. Por exemplo, é expectável que possa vir a ter grande impacto em todas as espécies que dependem, diretamente ou indiretamente, de cursos de água, devido à maior variabilidade na disponibilidade de água.

As ribeiras na região Mediterrânea são caracterizadas por terem um regime intermitente, que é determinado pela alternância entre períodos quentes, onde se registam temperaturas elevadas e reduzida precipitação, e períodos frios, onde as temperaturas são reduzidas e ocorre muita precipitação. Durante os períodos quentes as ribeiras apresentam um menor caudal, ficando frequentemente restringidas a pegos desconexos, que enchem no período frio e chuvoso, quando as ribeiras podem apresentar um regime torrencial. Esta heterogeneidade no volume do caudal das ribeiras, associado a outros problemas como destruição ou alteração de habitat, sobreexploração de recursos aquáticos, fogos e poluição, induzem grandes desafios ecológicos às espécies que habitam estes sistemas. Estes tipos de ecossistemas são extremamente importantes em termos de conservação, pois apresentam características únicas, albergando espécies muitas vezes diferentes dos habitats envolventes e, por isso, são áreas importantes para a conservação da biodiversidade local e mundial.

A lontra Euroasiática (*Lutra lutra*) habita um conjunto muito diversos de habitats, desde áreas costeiras até zonas ripícolas de interior (rios, ribeiras, lagoas, etc.). Em ambientes ripícolas, a espécie demonstra preferência por áreas pouco profundas e apresenta comportamentos de caça e de socialização em áreas com maior densidade e complexidade vegetal. A população global deste mesocarnívoros encontra-se em declínio, particularmente na Europa, devido a uma série de fatores, incluindo poluição, destruição e alteração do habitat, perseguição direta (caça) e captura acidental (redes de pesca). Apesar disso, a espécie está estável em Portugal e está listada como «Pouco Preocupante» no Livro Vermelho dos Mamíferos de Portugal. Os principais fatores de ameaça em Portugal espelham o contexto ambiental regional e incluem a destruição/alteração do habitat, principalmente devido a mudanças no regime fluvial, mortalidade por atropelamento, poluição. As mudanças associadas às alterações climáticas têm um grande impacto na zona do Mediterrâneo devido à intensificação dos extremos climáticos (períodos de seca e de cheia) e às alterações ambientais que estes induzem nas zonas ripícolas. A lontra é ecologicamente uma espécie muito importante porque representa o predador de topo nos ambientes aquáticos, exercendo um efeito regulador de algumas populações de presas. Também pode ser importante no controlo de espécies invasoras, como *Procambarus clarkii* que é atualmente uma das suas fontes de alimento preferida, ou de espécies de peixes não nativos, especialmente em barragens e reservatórios, onde a lontra também pode desempenhar um papel importante no seu.

O objetivo deste estudo foi contribuir para o conhecimento dos padrões ecológicos temporais e espaciais de uma população de lontra que habita uma região Mediterrânica com sistemas ripícolas de carácter intermitente. Foi igualmente avaliado de que forma estes padrões temporais se alteram consoante diferentes condições ambientais e quais os determinantes ambientais que determinam o uso espacial da paisagem e a abundância da espécie. Este estudo é particularmente importante para obter uma compreensão científica mais profunda da ecologia da lontra, tanto em termos espaciais como temporais, permitindo, assim, tomar decisões mais informadas sobre a forma mais eficaz de contribuir para a conservação desta espécie.

A monitorização da população foi realizada com recurso a câmaras de foto-armadilhagem, que foram instaladas longo de um total de 15km de cursos de água associados a galerias ripícolas, no Sudoeste de Portugal (Grândola). Estas câmaras foram instaladas com uma distância mínima entre cada de 500

metros, intervalo recomendado em estudos prévios em ambientes mediterrânicos. Estas câmaras estiveram ativas de Outubro de 2024 a Junho de 2025, totalizando um período médio de 252 dias de amostragem por câmara. Tendo em conta que no terreno foram instaladas 23 câmaras, o esforço de amostragem total foi de 5788 dias. Todas as câmaras foram colocadas em troncos de árvores localizados acima das margens da ribeira, e, posteriormente, orientadas em direção à ribeira, de forma maximizar a deteção das espécies de fauna que a usam (em particular a lontra) e evitar danos durante o período de cheias.

A recolha de dados ocorreu com um intervalo de 15 a 25 dias, dependendo das condições meteorológicas. Após essa recolha dos dados, as falsas deteções foram removidas (i.e. fotos sem indivíduos), e os registos que apresentavam a deteção de um ou mais indivíduos, foram separados por câmara e, dentro de cada câmara, por espécie. Para garantir que estes dados apresentavam independência temporal, foram selecionadas apenas as deteções com um intervalo 30 minutos entre cada, na mesma câmara. Os horários de cada deteção foram convertidos para hora solar para assim permitir a análise e a comparação dos padrões de atividade com dados de qualquer outra parte do globo.

Os padrões de atividade foram estimados através da utilização de estimadores de densidades de kernel. As uniformidades diárias dos padrões de atividade foram testadas com o teste de Rayleigh e as comparações entre os dois padrões diferentes, associada a contextos distintos (temperatura do ar, fases da lua e perturbação humana) foram efetuadas através do coeficiente de sobreposição e diferenças avaliadas com o teste Watson-Wheeler.

Para examinar os padrões espaciais de lontra foram utilizados dois tipos de modelos diferentes: Modelos de ocupação, para aferir os determinantes de ocorrência da espécie, e modelos de N-Mixture, que permitem avaliar os fatores que influenciam a abundância. Ambos os modelos incorporaram variáveis relacionadas com as características físicas e químicas da ribeira, estrutura da vegetação e perturbação humana, permitindo, assim, analisar quais as variáveis que mais influenciam a detetabilidade, ocupação e abundância da lontra nas ribeiras monitorizadas.

Não foram detetadas variações significativas dos padrões de atividade em diferentes contextos ambientais (Fases da lua, Temperatura do ar e Perturbação humana). Contudo, foi possível observar algumas tendências relevantes. Em noites com uma menor luminosidade lunar registou-se uma maior concentração de atividade ao meio da noite, possivelmente associado a uma vantagem predatória ligada a ausência de luz. Quanto à temperatura do ar, verificou-se uma maior intensidade e menor duração dos picos de atividade em períodos frios, sugerindo um aumento na procura de alimento para compensar as perdas energéticas, num menor período de tempo para evitar exposição ao frio e assim conservar energia. Em relação à perturbação humana, constatou-se um pico bastante acentuado a meio da noite, entre as 4h e 5h da manhã, possivelmente um ajustamento do comportamento deste predador para estar mais ativo num horário onde há menos atividade humana.

Em relação aos padrões espaciais de lontra foi possível observar que a deteção da espécie nas câmaras de foto-armadilhagem foi influenciada por variáveis como a profundidade da ribeira, largura da ribeira, densidade da canóia e altura da margem. Ribeiras mais largas aumentaram a deteção pois proporcionam um maior campo visual às câmaras e maior espaço de passagem para os animais. Águas mais profundadas reduziram a detetabilidade, pois existe a possibilidade de os indivíduos passarem por baixo de água e acabarem por não ser detetados. A densidade de canóia também afetou positivamente a deteção, facto provavelmente associado a uma menor entrada de luminosidade para a ribeira, que limita os reflexos na água que podem impedir a câmara de detetar alguns indivíduos. A altura da ribeira influencia de forma positiva a detetabilidade uma vez que em ribeiras com margens maiores, o posicionamento da câmara permite abranger um maior campo de visão, conseguindo assim otimizar a deteção de mais indivíduos.

A utilização de modelos de ocupação não permitiu identificar nenhuma variável que se influencie significativamente a presença de lontra. Contudo algumas tendências foram observadas. A probabilidade

de ocorrência da lontra é maior em zonas com menor profundidade, onde existe uma maior disponibilidade de alimento e condições de caça mais acessíveis.

Finalmente, os modelos de abundância relevaram que a abundância de lontra era maior em zonas com a presença de troncos caídos na ribeira (pvalue < 0.05). As estruturas em questão constituem um elemento que influencia a abundância da espécie. O mecanismo ecológico subjacente poderá estar relacionado com a função das estruturas em proporcionar uma maior acessibilidade às zonas mais interiores da ribeira, possibilitando a preparação de ataques e servindo igualmente como local de descanso entre tentativas de caça. Estas estruturas podem também ser utilizadas pelas suas presas, como local de abrigo, o que leva à lontra a associar este tipo de estruturas a disponibilidade de alimento, que assim as utilizam nas suas caçadas. Os resultados obtidos evidenciaram a capacidade de adaptação da espécie a diferentes condições ambientais, fornecendo informações para a elaboração de estratégias de conservação, contribuindo, deste modo, para a gestão sustentável das galerias ripícolas e a conservação da espécie e da biodiversidade local.

**Palavras-chave:** Ambientes ripícolas, Padrões de atividade, Padrões espaciais, Alterações climáticas, Variabilidade ambiental

## **Abstract**

Climate change poses a significant threat to global biodiversity, particularly in intermittent Mediterranean ecosystems, such as streams, by intensifying drought periods and flooding limiting water availability. The current study investigated the spatio-temporal patterns exhibited by *Lutra lutra* within riparian systems and the environmental and anthropogenic factors that may exert influence on these patterns. A total of 23 camera traps were set along mediterranean streams, 500 meters distance from each one, from October 2024 until June 2025. Temporal patterns of activity were estimated using kernel density estimators, Rayleigh tests, overlap coefficient analysis and Watson-Wheeler for test similarity in patterns between different environmental contexts. The evaluation of spatial patterns' determinants was conducted using occupancy and N-Mixture models, which incorporated variables such as the physical characteristics of the stream, vegetation structure, and human disturbance. The results indicated trends in activity patterns, with otters showing a nocturnal behaviour with some variation according to the environmental context, although these trends did not reach statistical significance; these were elevated activity levels during nocturnal periods coinciding with periods of reduced moonlight, more intense and brief activity peaks in cold periods, and adjustments in activity times in response to human disturbance. The spatial detection process was found to be influenced by various environmental factors, including the depth and width of the stream, riverbank height, and extent of canopy cover, but none of the tested drivers seemed to affect the occupancy patterns contrarily to the presence of fallen logs that was found to be positively correlated with the abundance of otters. These fallen logs provided structures that facilitated hunting, movement, rest, and recreation behaviours. The results demonstrated the species' capacity for adaptation to diverse environmental conditions and provided indispensable information for conservation strategies, thereby contributing to the sustainable management of streams and the preservation of this species and local biodiversity.

**Keywords:** activity patterns, spatial patterns, climate change, riparian systems, environmental variability

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## 1. Introduction

Climate change is a significant stressor that poses substantial threats to global and local biodiversity, inducing concerns regarding conservation (Tsang et al., 2020; Estrela-Segrelles et al., 2023). The impact of climate change varies geographically, with some regions experiencing more acute effects than others. European Mediterranean region is a notable example of a region that has experienced a pronounced and accelerated environmental alterations linked to climate change, as evidenced by the observed increase in temperatures, which has outpaced other parts of the globe (Giorgi & Bi, 2005; Lazoglou et al., 2024). These novel climate change conditions have the potential to exert a considerable impact, particularly on the riparian systems of southern Europe (CEC, 2009). Rising temperatures and decreasing precipitation are projected to result in an escalation and intensification of drought periods, potentially impacting wildlife dependent on water resources (Wetherald & Manabe, 1999; Parry et al., 2007).

Many streams of the Mediterranean region have an intermittent regime, which means that during the hot season, characterized by high temperatures and low rainfall, parts of the river dry up and become waterlogged (Vila-Gispert et al., 2005). The rainy season, on the other hand, is characterized by a drop in temperature and an increase in rainfall, which causes the streams to fill up again (Vila-Gispert et al., 2005). Besides the challenges induced by this irregularity of water availability, these streams and the associated riparian ecosystem have been subject to numerous threats and associated problems, largely attributable to factors such as habitat destruction or alteration, pressure on aquatic resources due to overexploitation of water, fires, and pollution (Gasith & Resh, 1999). The ecosystem in question is characterized by its unique properties, which encompass both terrestrial (e.g., the composition and structure of riparian vegetation and the surrounding landscape) and aquatic conditions (e.g., water availability, physical-chemical characteristics of the water, and stream structure—depth, width, etc.). These characteristics collectively contribute significantly to the biodiversity values of the ecosystem. (Bonada & Resh, 2013). Some of these values are unique, including endemisms (e.g., Iberian fishes – *Iberochondrostoma almacai*, *Squalius torgalensis*; Magalhães et al., 2023 – or mammals – *Neomys anomalus*; Mathias et al., 2023–) and species of conservation concern (*Lutra lutra*, considered by the IUCN as Near threatened, with populations largely depleted ; Loy et al., 2021) The combination of their exposition to climate change effects, the substantial anthropogenic activity they are subject to, and the singular biodiversity values make riparian systems highly threatened, and thus should be prioritized for protection and conservation (Blondel et al., 2010; De Figueroa et al., 2012).

The Eurasian otter *Lutra lutra* is a species of significant ecological importance within riparian systems (Bedford, 2009). It is a species that functions as a top predator (Remonti et al., 2007), and despite its trophic flexibility (Clavero et al., 2003), it is essential for controlling the trophic chain, since it regulates prey density and regulates various lower-level predators (Wallach et al., 2015). Furthermore, the species possesses a capacity for seed dispersal, as evidenced by Latorre et al. (2022). *Lutra lutra* (Class Carnivora, Family Mustelidae) is a semi-aquatic mammal, characterized by a hydrodynamic body shape, with an elongated body and a large cone-shaped and a pointed tail (Kruuk, 2006). The fur of the *Lutra lutra* provides it with significant insulation from the low temperatures of its aquatic habitat and the surrounding environment (Larivière & Jennings, 2009). This species shows sexual dimorphism, with males being larger than females (Larivière & Jennings 2009). The otter's diet consists primarily of fish, although it has been observed to consume birds, amphibians, small mammals, and fruits (Brzeziński et al., 1993; Taastrøm & Jacobsen, 1999). However, the diet of *Lutra lutra* varies depending on the region in which it is distributed, reflecting the availability of food sources in each area (Pedroso et al., 2014). *Lutra lutra* is a nocturnal animal with a crepuscular tendency (Kruuk, 2006.) and is typically solitary

and territorial (Quaglietta et al., 2014). These territories are passively defended through the emission of a distinctive odor by scent glands, which facilitates inter-individual communication and the delineation of territorial boundaries (Kruuk, 2006). The Eurasian otter is found in both coastal areas, wetlands and in riparian systems linked to rivers and streams (Hung & Law, 2016; Pedroso N.M. & Santos-Reis M., 2023). In riparian systems areas, the species exhibits a preference for shallow areas (0-3m) (Kruuk and Moorhouse 1990) and it displays behaviors such as playing and hunting in areas with a higher plant density and complexity (Fumagalli, 1995). It is ecologically very important because it plays the role of top predator, which is important for population control. In addition, it can delay the invasion of the American mink *Neovision vision*, through direct competition, and studies have shown that *Lutra lutra* manages to outcompete and force the *Neovision vision* to change its diet (Bonesi et al., 2004; Gonçalves S, 2012). It may also be important in controlling the invasive species *Procambarus clarkii*, which is currently its preferred food source (Beja, 1996). Non-native fish species are also a major problem, especially in dams and reservoirs, and *Lutra lutra* can also play an important role in controlling these species (Ribeiro et al., 2007).

With an extensive distribution, spanning from Portugal to Japan across three continents (Europe, Africa, and Asia) the Eurasian otter is, nevertheless, classified as "Near Threatened" by the IUCN (International Union for Conservation of Nature), a designation it has held since 2004 (Roos et al., 2015). The global population of otters is in decline, particularly in Europe, due to a range of factors including pollution, habitat destruction and alteration, direct persecution (hunting) and accidental capture (fishing nets) (Koelewijn et al. 2010). Despite this scenario, the species populations in Portugal are considered stable and the otter is listed as "Least Concern" in the Red Book of Mammals of Portugal (Pedroso & Santos-Reis, 2023). The distribution of the species extends from the northern to the southern regions of the country, and this decline in category classification is believed to be associated with the introduction of the Louisiana crayfish *Procambarus clarkii* (Girard, 1852), which has led to increased food availability (Delibes & Adrián, 1987; Fialho, 2016). In Portugal, the otter has some peculiarities, such as its diet being mainly composed of crustaceans and fish (Pedroso & Santos-Reis, 2023), unlike in other places where it is found, where the diet is clearly dominated by fish (Kruuk 2006). The main threat factors for otters in Portugal are habitat destruction/alteration, mainly due to changes in the river regime, roadkill's and bycatch mortality in fishing nets, pollution and environmental changes due to climate change (Pedroso et al., 2014). The latter has a significant impact on Mediterranean systems due to changes and intensification of drought periods (Ruiz-Olmo et al., 2007). According to Schweiger and Frey (2021), climate change has the potential to impact the daily activity patterns of certain species of mammals.

Considering the climate change scenario and its effects on Mediterranean streams, together with the functional and conservation role of otters, this study is focused on assessing otter's temporal and spatial ecology patterns in a landscape with intermittent regime Mediterranean streams. Thus we aim to 1) estimate otter's activity patterns in a Mediterranean area where stream are characterized by intermittent regimes; 2) assess how the activity patterns vary in different environmental conditions (i.e. air temperature, moon phases), and 3) identify the environmental drivers (e.g., stream and vegetation structure, disturbance) shaping otters occupancy and abundance patterns.

We defined several hypotheses targeting otters temporal and spatial dimensions of their niche. Regarding the temporal dimension, we hypothesize that:

- (a) It is anticipated that the activity of *Lutra lutra* will be predominantly nocturnal (Beja, 1996).
- (b) Otters' activity patterns will be influenced by the moon light, because the amount of night light will shape their predation success and their detectability by prey and Humans; thus, it is anticipated that otter activity will decline in tandem with increased moonlight (Willems, 2020).
- (c) It is anticipated that there will be an influence on otter activity patterns when temperatures decrease (Adams, 1971), as lower temperatures cause greater energy loss in these animals. It is hypothesized that otter activity will decrease at lower temperatures.
- (d) It is anticipated that an increased human presence will influence otter activity patterns, as otters tend to avoid contact with humans (Calzada et al., 2022). It is hypothesized that an increase in human presence will result in a decrease in otter activity.

We also defined the following hypothesis related with otters' spatial patterns:

- (1) It is anticipated that otters will utilize pool areas with low current speeds and shallow waters (Basto et al., 2011) and narrow banks (Cho et al., 2009) to a greater extent, and areas with a lower bank slope (Prenda & Granado-Lorencio, 1996) and with a lower bank height (Wang et al., 2021), as these characteristics facilitate access to the stream and enhance efficiency in hunting (Wang et al., 2021);
- (2) It is expected that otters will exhibit a higher prevalence in areas with elevated vegetative complexity (Fumagalli et al., 1995), i.e., areas with a higher percentage of canopy cover and a greater presence of logs on the banks and in the stream (Prenda & Granado-Lorencio, 1996), as well as a higher percentage of vegetation on the banks of the stream (Bas et al., 1984);
- (3) we also expect a greater affluence in areas with less anthropogenic activity (Cortés et al., 1998), where we find less otters numbers the closer we get to roads (Philcox et al., 1999) and dams (Ruiz-Olmo et al., 2001; Pedroso et al., 2013).

Fulfilling the above-mentioned objectives is of particular significance to obtain a deeper scientific understanding of the otter's adaptation to the environmental context of southern Portuguese landscapes, thereby enabling more informed decisions regarding any management action affecting riparian areas, which may thus influence otters' conservation outcomes.

## 2.Methods

### 2.1 Study area

This study was carried out in Serra de Grândola (Alentejo) ( $38,11090^{\circ}$  N,  $8,52874^{\circ}$  W), where four streams were selected for this study: Ribeira de Castelhanos, Ribeira de Grândola, Ribeira de Corona and Ribeira do Lousal. All the selected streams belong to the Sado basin.

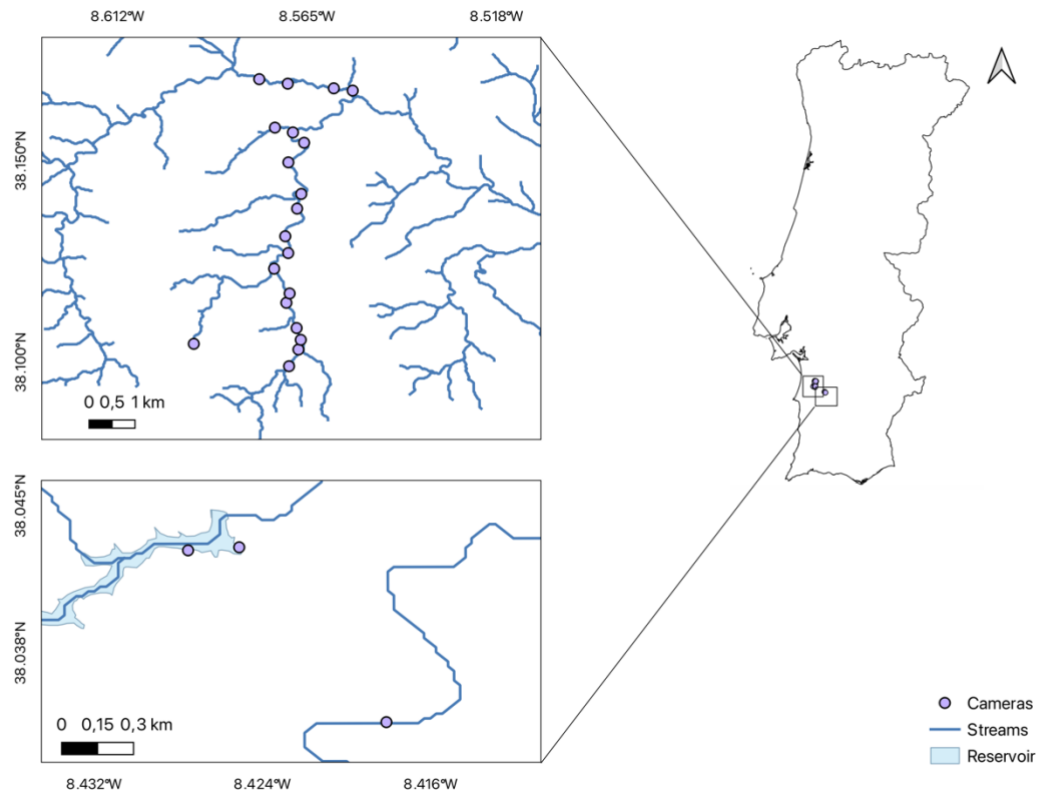


Figure 1. Study area and cameras represented in Alentejo, Setubal district, Portugal. The upper square is located in Northern Serra de Grândola, near Grândola city, where 20 camera traps were set. The lower square is located in Lousal (south of Grândola), where 3 camera traps were installed.

This location is distinguished by its gently rolling terrain, exhibiting small variations in altitude (ranging from 0-370m) and slopes of 0-15% (Correia & Santos-Reis, 1999; Rosalino et al., 2005). The region's climate is characterized by typical Mediterranean conditions, with the annual precipitation ranging from 600mm/year to 1,050mm/year, with fluctuations contingent upon the latitude and altitude (Fernandez et al., 2016). The mean annual temperature is averaging  $15.6^{\circ}\text{C}$  (Correia & Santos-Reis, 1999), with considerable variation between seasons. In winter, temperatures can drop below zero, while in summer, they sometimes exceed  $40^{\circ}\text{C}$ . The Mediterranean climate shapes the intermittent regime of the regions streams, whereby the summer months are defined by high temperatures and low precipitation, which results in the desiccation of certain areas of the streams. Conversely, the winter months are distinguished by a considerable amount of precipitation, which replenishes water to all parts of the stream. This location is associated with a typical Mediterranean landscape, where traditional cork oak forests

(montado) dominate, although there are some areas where monoculture production of Eucalyptus occur. The riparian vegetation is dominated by willows (*Salix atrecenerea*), poplars (*Populus nigra*), hawthorns (*Crataegus monogyna*), and alders (*Alnus glutinosa*) (Costa & Santos-Reis, 2002). In terms of anthropic activities, cork extraction, sheep and goat grazing and the exploration of non-wood products (e.g., mushrooms, honey, aromatic plants) are the most common (Geri et al., 2009).

## 2.2 Camara trapping

### 2.2.1 Sampling design

The distance between cameras was selected based on the necessity to optimize otters' detections to allow the following modelling procedures but also following other studies targeting otters in Mediterranean environments (Lerone et al., 2015; Gil-Sánchez & Antorán-Pilar, 2020) or medium-large mammals in general (Yang et al., 2025). *Lutra lutra* exhibits notable specificities when sampled using camera trapping (Kuhn & Meyer, 2009; Lerone et al., 2015), however it was therefore decided that 500 meters between cameras would be an optimal setting for sampling otters in the study area, covering 15km of streams. The 23 cameras were operational in the field from October 2, 2024, to June 12, 2025, resulting in an average total of 252 sampling days per camera (see Table 1). However, three cameras (6, 30 and 32) exhibited 20 days less number of capture days compared to the total number of days captured by all cameras. The total duration of the sampling effort is 5,788 camera-days.

Table 1. Sampling effort days and installation date by camera.

Cameras	Sampling date	Effort days
5	02/10/2024 – 12/06/2025	254
6	24/10/2024 – 12/06/2025	236
7	02/10/2024 – 12/06/2025	254
12	02/10/2024 – 12/06/2025	254
18	02/10/2024 – 12/06/2025	254
20	02/10/2024 – 12/06/2025	254
21	02/10/2024 – 12/06/2025	254
25	02/10/2024 – 12/06/2025	254
29	02/10/2024 – 12/06/2025	254
30	22/10/2024 – 12/06/2025	236
32	22/10/2024 – 12/06/2025	236
34	02/10/2024 – 12/06/2025	254
38	02/10/2024 – 12/06/2025	254
42	02/10/2024 – 12/06/2025	254

44	02/10/2024 – 12/06/2025	254
53	02/10/2024 – 12/06/2025	254
57	02/10/2024 – 12/06/2025	254
61	02/10/2024 – 12/06/2025	254
62	02/10/2024 – 12/06/2025	254
64	02/10/2024 – 12/06/2025	254
65	02/10/2024 – 12/06/2025	254
66	02/10/2024 – 12/06/2025	254
69	02/10/2024 – 12/06/2025	254
<i>Total</i>	02/10/2024 – 12/06/2025	5788

### 2.2.2 Camera-trap settings

A total of 23 trail cameras (model *Browning Dark Ops HD Pro X BTC-6HDPX*), with IR flash were deployed within the study area. Our focus was to obtain data on the presence of otters and other mammals using the watercourse, but we also wanted to observe specific behaviors exhibited by these individuals. Therefore, we deployed fourteen cameras in trail mode with a 30-second delay and nine cameras in video mode with a 10-second delay. Those that were set in the trail mode were programmed to take three consecutive photos every time they were activated.

### 2.2.3 Positioning

The cameras were strategically positioned in the trees adjacent to the stream to guarantee that their height exceeded the banks of the streams. This sampling design feature ensured that during periods of high rainfall, the cameras remained above the waterline, thus avoiding their submersion and preventing any damage to the material linked to flooding. After the placement of the cameras, the devices were oriented in the direction of the stream - perpendicular when possible and without any vegetation that could prevent a direct animal detection - with the objective of optimizing the field of vision of the camera and maximizing the observation and detection of animals utilizing the watercourse (Figure 2.).



Figure 2. The representation of the field of view captured by one camera trap used in this study, with a detection of *Lutra lutra*. This record was captured on April 27, 2025, in camera number 38.

#### 2.2.4 Data collection

From October 2024 to May 2025, all cameras were active in continuum and data collection was conducted at all sampling points with a frequency of every 15 to 25 days, depending on the weather conditions. During this process, the data stored on SD cards was extracted and transferred to a disk. The disk was then "cleaned" to ensure that sufficient space remained for the next data collection. Images of false shots were eliminated from the dataset, and the images that exhibited the presence of an individual or individuals were initially separated by the cameras in which they were recorded. Each photo containing an animal record was screened to identify which species were present. Subsequently, within each camera, photos were grouped by species. This process culminated in the generation of a file or folder containing the species identified in each camera. This approach allows us to identify which species were detected in a particular location and when, using the metadata of the photos and videos.

## **2.3 Otter survey**

### **2.3.1 Drivers of otter occurrence and abundance**

In order to assess the drivers of otter occurrence, abundance, and activity patterns, a number of variables were initially selected based on their potential to affect the distribution of this species, as indicated by previous studies (Kruuk & Moorhouse, 1990; Fumagalli et al. 1995; Mucci et al., 2010). Four variables were collected to test their effect on activity patterns: air temperature, moon phases, human disturbance, and daily cycle (Table 2).

To test the factors influencing the otter spatial patterns, three groups of variables were initially selected: 1) Chemical and physical characteristics of the stream; 2) Vegetation structure; and 3) Human disturbance. The chemical and physical characteristics of the stream group include the Stream type, the width and depth of the stream, water velocity, riverbank height and slope and stream substrate. Vegetation drivers included the presence of fallen logs on the bank, other woody structures in the water, dominant vegetation type, within a radius of 5 meters and the percentage of vegetative cover type and canopy coverage. Finally, the human disturbance was assessed based on the distance to roads and dams, and evidence of people's presence. The measurement of all variables was carried out in the field on every occasion that camera trap data was collected.

Table 2. Variables tested as factor influencing the temporal pattern of *Lutra lutra*, the rationale of their selection and the supporting references.

Variable	Description	Type and data origin	Explanation	References
Climatic variables	Air temperature	Numeric; Air temperature variable was measured on-site by collecting data from a climate station located in the center of the study area, at Herdade da Ribeira Abaixo, Serra de Grândola (38.10814° N, 8.56910° W).	This species may be less active in colder temperatures, as individuals may minimize heat loss by being active for shorter periods of time.	(Stiegler et al., 2023) (Guiden & Orrock, 2020)
Moon	Moon phase	Categorical (“New to half” and “Half to full”); The phases of the moon were recorded using the date collected by the camera trap.	This variable was used to determine whether moonlight influenced otter activity in other regions of the world with mammals.	Bischof et al. (2024)
Human disturbance	Signs of human disturbance	Categorical (“Presence” and “No presence”); Human presence was measured using several parameters: Distance to roads and dams (linear distance between camera-traps and the nearest road/dams). Evident signs of human presence (e.g., houses, buildings, and infrastructure); Presence of monoculture areas within a 50-meter radius around each camera	This was measured, and then it was concluded whether the road was close enough to influence individuals. Areas close to dams show some level of human presence for leisure and work. All these parameters were then considered, and a conclusion was reached for each sampling point as to whether it was under possible human pressure.	(Philcox et al., 1999) (Penteriani et al., 2025)

Table 3. Variables tested as factors influencing occupancy/abundance, grouped by ecological hypothesis, together with the rationale for their selection.

Characteristic of habitat	Description	Type and data origin	Expected Influence	Explanation	References
H1- Chemical and physical characteristics of the stream	Stream type	Categorical (“Pool” or “Rapid”)	Pool	Otters often utilize pool areas because as pool characteristics facilitate access to the stream and enhance efficiency in hunting.	(Wang et al., 2021)
	Width of the stream	Numeric Width was determined using a sensor equipped with a red light, which allowed for the calculation of the distance between the device and the opposing bank of the stream.	+	The presence of otters in proximity to narrow streams is well-documented, as such streams offer facile access to both the stream itself and the surrounding land, providing optimal conditions for rest.	(Cho et al., 2009)
	Depth of the stream	Numerical; The depth was gauged at the center of the stream with the aid of a measuring stake. The aforementioned variables were measured during all data collections in order to obtain an average value, taking into account the considerable fluctuations observed throughout the year and across seasons.	-	Otters have been observed to inhabit areas of fluvial environments characterized by a low depth, a preference that is presumably facilitated by the enhanced accessibility of their prey within such habitats.	(Kruuk & Moorhouse, 1990) (Basto et al., 2011)
	Water velocity	Categorical (“Slow”, “Medium” or “High”) The velocity of the water current was determined through the implementation of a measurement technique that involved the establishment of two points	Slow	Otters have been observed to inhabit slow-water streams, a habitat that offers both the advantages of facilitating the capture of their prey and conserving energy.	(Basto et al., 2011)

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	at a distance of one meter apart. An object was positioned at the initial point and its passage was recorded when it reached the terminal point. Utilizing the obtained data, it is feasible to calculate the velocity of the current. It was then transformed into a categorical variable.		
Slope	Numeric (%) The slope was measured using a slope meter. This entailed first placing a flat surface in the measurement area. Then, the meter was positioned over this surface to take the measurement.	-	Otters have been observed to inhabit streams characterized by a gentle slope, a feature that facilitates their entry and exit, thereby supporting their feeding habits. (Prenda & Granado-Lorencio, 1996)
Stream substrate	Categorical (“Soil”, “Soil with rocks” or “Rocks”) The stream substrate was collected and defined directly, thus resulting in its division into different classes and typologies, as illustrated in Table 2.	Soil	Otters exhibit a preference for streams with a finer substrate, as the presence of a thicker substrate facilitates the concealment of their prey. (Barbosa et al., 2001)
Riverbank height	Numeric; The height of the bank was measured using the same sensor that had been employed to measure the width of the stream. The sensor was positioned in close proximity to the bank and oriented in the direction of the water, ensuring that the line of the sensor and the surface of the water formed a 90° angle. This configuration was necessary to ensure the accurate measurement of the bank’s height.	-	(Wang et al., 2021) Otters have been observed to utilize areas of the river characterized by lower banks as entry points to access the river’s resources.

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H2- Vegetation	Fallen logs on the bank structures in the water	Categorical (“Logs” or “No logs”); This variable was determined by visual estimation, given the ease with which it could be assessed.	Logs	There appears to be an association with otters and logs on the water because is utilized for play and hunting and playing purposes.	(Fumagalli et al. 1995).
	% of vegetative stream cover type	Numeric (%); The measurements were obtained through visual estimation by a group of observers, who subsequently calculated the mean to enhance the reliability of the data.	-	The presence of vegetation cover has been demonstrated to be associated with the enhancement of suitable hiding places for otter prey. The presence of abundant vegetation along the stream has been demonstrated to negatively impact the efficiency of hunting.	(Prenda & Granado-Lorencio, 1996)
	% canopy coverage	Numeric (%); The measurements were obtained through visual estimation by a group of individuals, who subsequently calculated the mean to enhance the reliability of the data.	+	The presence of canopies has been demonstrated to be associated with improved conditions for otters, as they provide protection and enhanced shelter.	(Kruuk et al., 1990)
H3- Human disturbance	Distance to roads	Numeric Distance to roads were determined using the "Proximity (Raster Distance)" tool in QGIS.	-	This approach was employed due to the existing literature indicating that otters are victims of roadkill, as otters seem to avoid it.	Philcox et al. (1999)
	Distance to dams	Numerical; Distance to dams were determined using the "Proximity (Raster Distance)" tool in QGIS.	-	Dams have been shown to have adverse effects on species, including the reduction of river connectivity, alterations in prey	(Mucci et al., 2010) <b>(Pedroso et al., 2013)</b>

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Evidence of people's presence	Categorical (“Human presence” or “No human presence”); This variable incorporated infrastructure data, indicating the presence of humans within a 50-meter radius of infrastructure.	No	species and availability patterns, as well as the destruction of riverbanks.	(Barbosa, A.M et al., 2001)
Landscape composition within a radius of 30-50m	Categorical (“Natural” or “Monoculture”); The type of landscape within 50 meters of the sampling point was also ascertained through the utilization of QGIS, a geographic information system, to determine the level of artificialization of the area.	Natural	The positive effect of natural landscapes on species has been demonstrated.	(Marcelli & Fusillo, 2009)

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## 2.4 Statistical analysis

A comprehensive analysis was conducted to assess the drivers of temporal and spatial activity patterns exhibited by otters. This analysis employed a range of methodological approaches and analytical techniques. For both cases, the software 2024.12.0.467 RStudio (RStudio Team, 2024) and R 4.4.2 version (R Core Team, 2021) were utilized. Temporal analysis employed the R package "camtrapR" (Niedballa et al., 2016) to generate an otter presence matrix (otter detection event per camera-trap). The "solaR" package was utilized to convert the time to solar time (Oscar Perpiñán, 2012), and the "suncalc" package (Thieurmél & Elmarhraoui, 2023) was used to calculate solar and lunar positions. The "circular" package was selected and used for all analysis that are involving circular statistics (Agostinelli & Lund, 2025) and the "overlap" package to estimate the overlap of temporal activity patterns. The "unmarked" package (Kellner KF. et al., 2023) was utilized for all spatial modelling procedures, as it was designed to analyze ecological data collected using camera-traps, incorporating imperfect detections in the analysis. The "MuMIn" (Bartoń K., 2025) package was used in the model selection and averaging procedures.

### 2.4.1 Temporal analysis

The overall otter presence data obtained by using the camera traps was processed to create a dataset matrix. To guarantee that only temporally independent data would be utilized in the analysis, records registered in the same camera with a minimum of 30-minute difference between each other were the only ones used in the analysis. Subsequent to the creation of the matrix containing the independent otter presence records (i.e. time at which each record was registered), it was necessary to convert the standard time (i.e. PT time zone) to solar time. This conversion was required to facilitate a comparison with the data from different locations and time zones (Brock, 1981). For every day we managed to record an otter I any of the cameras, we calculated the sunrise and sunset times.

The estimation of otter's activity patterns was based on the Ridout and Linkie (2009) proposed approach, that estimates a non-parametric approach to assess the probability density function of detections per hour (kernel density estimator). It assumed that likelihood of detecting otters at any time is equal. The generated kernel density curves were used to assess the overall activity patterns, but also how this pattern may vary with the moon phase, different temperatures and distinct human disturbance contexts. The Rayleigh's test (Wilkie, 1983) was performed to evaluate the uniformity of the circular distribution (i.e., assess if otters showed a random activity pattern throughout the circadian cycle). To compare the activity patterns between data subsets (e.g. moon phases, different temperatures and distinct human disturbance) we estimated the temporal coefficient of overlap ( $\Delta 1$ ) (Inman & Bradley, 1989), using a resampling technique. This coefficient is employed to facilitate a comparison of the overlap of two activity patterns, as it ranges from 0 (no overlap) to 1 (complete overlap) (Ridout & Linkie 2009). The uncertainty was estimated using bootstrapping, a statistical method that generates multiple datasets to calculate a confidence interval. In this study, 999 datasets were generated, and the 95% confidence interval was determined. We used the  $\Delta 1$  overlap coefficient as it was demonstrated that it is generally more adequate for small sample sizes (Ridout & Linkie, 2009). The Watson-Wheeler test (Wheeler & Watson, 1964) was used to compare two circular distribution datasets (i.e. activity patterns) and ascertain whether the two patterns were different, i.e. with a p-value < 0.05.

## 2.4.2 Data preparation

Following the collation of all variables deemed pertinent to the study of otter spatial patterns, a detection history was created with an "occasion Length" of 30 days, using the "camtrapR" package. The entire study period was divided into groups of 30 day to generate two different matrixes: species detection (0/1) per camera-trap per occasion (14 occasions); and number of detections per camera-trap per occasion (14 occasions).

The detection history was transformed into a data frame, with the selected variables that characterize each camera-trap location (see table 2) being added. In the subsequent phase of the data preparation, an investigation was conducted into the collinearity between the variables. The Spearman's correlation coefficient (Spearman, 1904) was utilized to ascertain the correlation between variables and those variable pairs that reach values higher than  $|0.7|$  were considered highly correlated. This procedure allows us to identify dependency between correlations and thus avoid using highly correlated variables in the same model, which could lead to unstable coefficient, misleading interpretations or predictive inaccuracy (Schober et al., 2018; Hanberry 2024). However, no no significant correlation was detected between any variables (Figure 3.). Thus, we also estimated the Variance Inflation Factor (VIF) (Beaumont et al., 1981), in order to confirm if multicollinearity existed in our dataset (Belsley, 1991). Using Zuur et al. (Zuur et al., 2007) suggestion all variables with  $VIF > 5$  were excluded from the analysis. Only the variable "stream type" was removed. Subsequently, the numerical variables were standardized into z-scores in order to facilitate coefficients interpretation (Moeller, 2025).

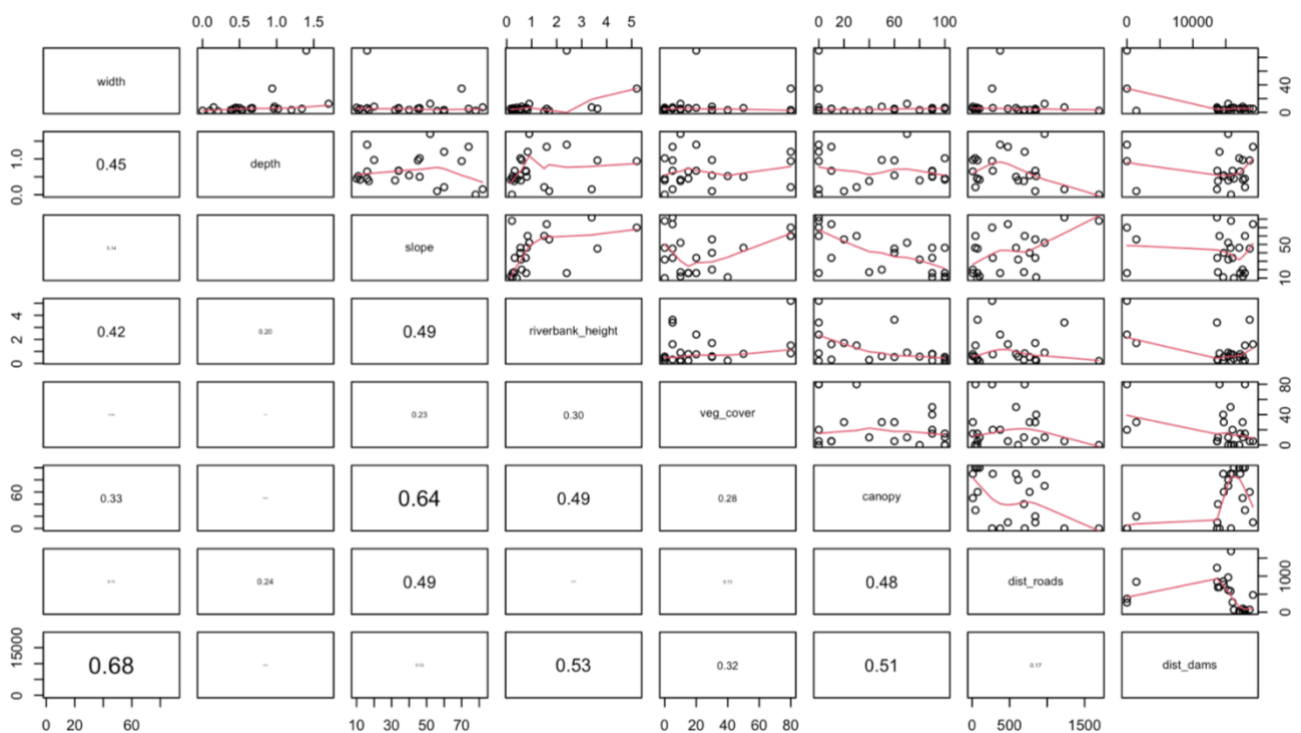


Figure 3. Spearman correlation between numerical variables.

Table 4. Variable selection criteria utilizing Variable inflation factor number of variables.

<b>Variable inflation factors</b>	
<b>Variable</b>	<b>VIF</b>
Stream type	5.675
Width	2.792
Depth	3.409
Water velocity	2.481
Slope	2.805
Stream substrate	2.271
Riverbank height	4.130
Logs	2.817
Vegetation cover	1.648
Canopy	3.206
Distance roads	3.598
Distance dams	3.020
Land composition	1.828

### 2.4.3 Spatial modeling analysis

To assess otters' spatial patterns, we used two different types of models, all based on data collected with the camera-traps: occupancy models and N-Mixture models. The first of these models predict the probability of a species' presence in a location, given the environmental or anthropogenic variables present in the study area, considering that detection probability is not 1 (MacKenzie et al., 2002). These models analyze data using a presence/absence matrix (0-1) over a specified period of time (several contiguous occasions). These presence/absence values are then related to the variation of the candidate variables, while coping with detectability variation between sampling sites., estimated through a logit function (MacKenzie et al., 2002). Occupancy models are built in two phases: first we estimate the variables influencing detectability, while maintaining occupancy constant; secondly we estimated the factors influencing occupancy, while incorporating the variables that affect detectability, that were assess in the first phase (MacKenzie et al., 2002). The objective of these occupancy models is to demonstrate, through model-based visualization, the influence of the variables tested on otter's occupancy, to identify those with significant positive and negative influences.

N-Mixture Models (Royle, 2004) were employed to analyze the factors shaping otters' abundance variation. These models have the capacity to assess which variables are affecting both the detectability and abundance of the target species (Royle, 2004). The input data for N-mixture models differ slightly from that used on occupancy models. Instead of using a presence/absence matrix (0-1), N-mixture models use a matrix representing the number of detection of individuals in each time period (or occasion). As for occupancy models, the detection of the species can be greatly influenced by the environmental context found at the sampling sites (Joseph et al., 2009). The estimation of the probability

that a specimen of this species will be recorded by a camera trap is made by way of a logit link function (McCullagh & Nelder, 1989). N-Mixture model are built following the same structuring phases described above for occupancy models, In the context of assessing a species spatial patterns N-Mixture model allow to go further (than modeling the occupancy of a species) in understanding how wildlife used the landscape as it allows determining which covariates are influencing the abundance of a species, which is a more informative population metric than the probability of a species occupy a specific site (Joseph et al., 2009).

### 2.4.3.2 Detectability

In order to assess which variables were affecting otter detectability, a series of models were created with all possible combinations of variables. These included six variables linked to the chemical and physical characteristics of the stream, as well as vegetation variables (see table 2): three physical and chemical variables of the stream (riverbank height, width and depth) and three of the vegetation (canopy, vegetation cover, and presence of logs). The human presence variable was not included in the detectability analysis because it was assumed that its effect on detectability will be negligible. Subsequently, the models were ranked according to their AICc value (Akaike Information Criterion, adapted for small samples; Burnham et al., 2011). The variables included in the models with  $\Delta AICc < 2$  (i.e. difference in AICc values between each model AICc and the lowest AICc values; Burnham et al., 2011) were selected as drivers of detectability variation and thus included in the subsequent occupancy models. Therefore, for the otter detectability model, only . The detection model selection procedure was consistent across both data analysis techniques, namely occupancy and N-Mixture models (abundance).

### 2.4.3.3 Occupancy and Abundance

In order to identify which variables exert an influence on otter occupancy/abundance, we consider eight variables, grouped in three clusters (three chemical and physical variables of the river; three of the vegetation; two from human presence) as candidates drivers. The variables included in each cluster were, respectively: riverbank height, width, and depth; canopy, vegetation cover, and the presence of logs; distance to dams and distance to roads. They were used to test three distinct hypotheses, explaining otter's occupancy and abundance variation: *H1—Physical and chemical characteristics of the stream; H2—Vegetation; H3—Human presence*. A final hypothesis was defined that encompassed a combination of all the variables that were included in the best models of the previous hypotheses and whose confidence interval did not include the zero, i.e., we informative variables (Arnold, 2010). In total, 4 groups of models were created, linked to each working hypothesis. For each hypothesis, we identified all models with a  $\Delta AICc < 2$ , which were considered the best models. We compared the AICc of the best models of each hypotheses and considered the hypothesis with more support that that included the model with the lowest AICc value. This approach enabled us to identify the most suitable set of models and the hypothesis that exerted the most significant influence on otter abundance/occupancy. Subsequently, the optimal set of models, characterized by the lowest overall AICc value, was identified. Variables present within these models with a confidence intervals (95% CI) that did not include the 0 were considered informative variables and those more influential (with statistical support) in shaping occupancy and abundance variations. The coefficient, standard error, and p-value of each variable were also calculated. Finally, the goodness-of-fit of the best model,

corresponding to the one with the lowest AICc or Overall $\Delta$ QAICc value. was calculated, which serves to assess whether or not the model is suitable for representing the observed data. The c-hat was also estimated, as a metric that allows us to test whether or not the model presents overdispersion (Guthery et al., 2003).

## 4.Results

### 4.1 General results

During the 254 monitoring days, the 23 cameras allowed a total sampling effort of 5,788 camera-trapping days, which allow us to register 45 otter records ( $n = 45$ ), as well as other species. However, these records were concentrated in just a few cameras (Table 5).

Table 5. Number of records of *Lutra lutra* per camera-trap\*

Camera number	Records
7	4
20	2
25	1
30	5
34	1
38	17
42	9
44	5
53	1
<b>Total</b>	<b>45</b>

\* The cameras without any otter detection during the sampling period have not been represented in this table .

### 4.2 Otter activity patterns

#### 4.2.1 *Lutra Lutra* general activity pattern

As anticipated, *Lutra lutra* exhibited a predominantly nocturnal activity pattern (Figure 4.), showing a non-uniform activity within circadian cycle ( $pvalue = 3.86 \times 10^{-7}$ ) and two distinct periods of increased activity: after sunset and before sunrise, indicating that the otter exhibited a bimodal activity pattern. The intensity of this two distinct periods is different, with the later, at early morning hours, experiencing a more pronounced peak.

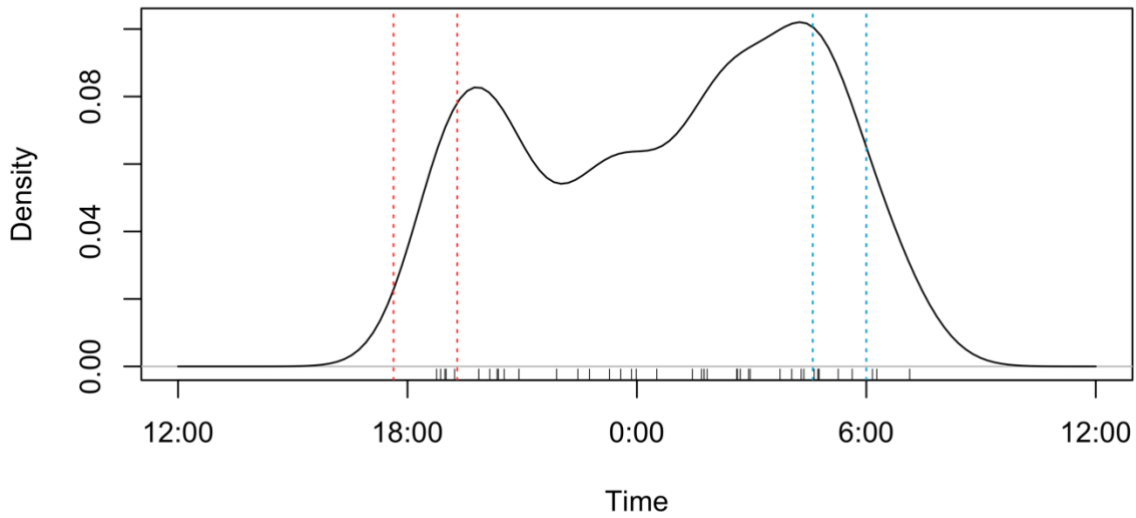


Figure 4. Kernel density estimate of *Lutra Lutra* activity, during a full 24 hour day. Vertical dashed red line represents sunrise variation during the monitoring period (red lines) and blue dashed vertical line sunset variation (blue lines). Small vertical lines above x-axis represent otter detection records.

## 4.2.2 Temporal activity patterns in different environmental contexts

### 4.2.2.1 Moon phase

This comparison between periods of higher visibility at night (half to full) and periods with reduced visibility (new to half) reveals visual variations in otter activity patterns. When the amount of night light is higher, and thus visibility is enhanced, the observed patterns do not deviate significantly from the species' typical patterns, described before. The species exhibits a bimodal pattern, with two peaks of activity: one at the beginning of the night and the other at the end of the night. In contrast, in periods of reduced visibility we observe significant deviations from the typical activity patterns of the species, with only a single peak, occurring in the nocturnal period ( $\pm 1$  AM). However, due to the fact that the Watson-Wheeler test yielded a p-value of 0.553 ( $>0.05$ ), it was only possible to observe certain trends. This result indicates that, from a statistical perspective, these two groups are equivalent. The overlap coefficient between both moonlight contexts ( $\Delta I = 0.81$ ), indicates a substantial overlap between the two night conditions, although we can see differences in their pattern. In both conditions the Rayleigh's test showed that the species activity was non-uniform across a 24-h circadian cycle ( $Z_{\text{new to half}} = 3.27 \times 10^{-5}$ ,  $p < 0.05$ ;  $Z_{\text{half to full}} = 0.01$ ,  $p < 0.05$ ), thereby indicating a statistically significant discrepancy in activity throughout the diurnal and nocturnal periods.

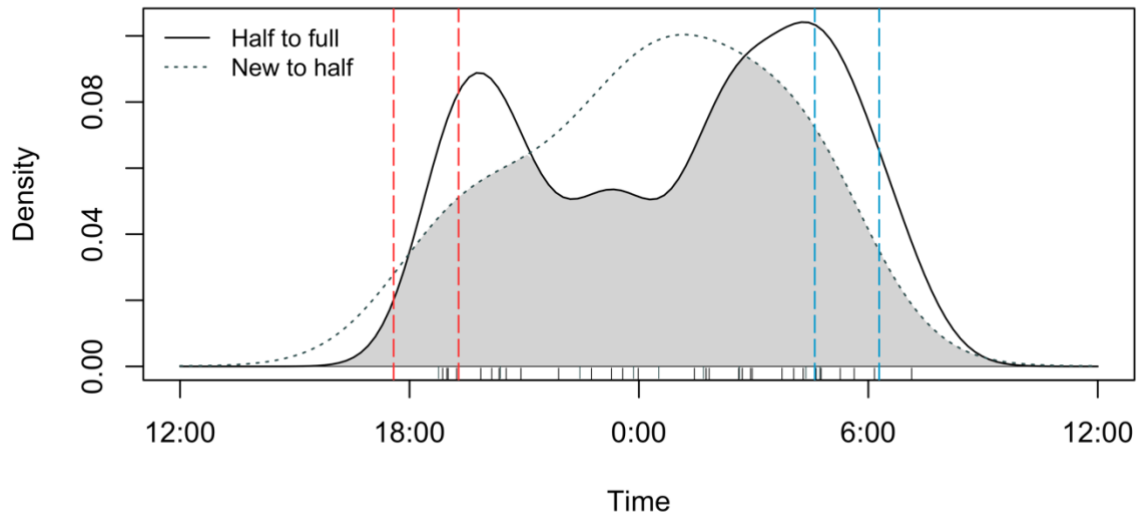


Figure 5. Estimated temporal patterns of *Lutra lutra* in different Moon light contexts. Dotted line corresponds to "New to half" moon conditions, corresponding to the period of no moon luminosity to 50% of moon luminosity. Straight line corresponds to "Half to full" moon context that corresponds to 50% and higher of moon luminosity. Vertical dashed red line represents sunrise period and blue dashed vertical line represents sunset. Small vertical lines above x-axis represent otter detection records.

#### 4.2.2.2 Air temperature

We assessed otter activity patterns in warmer air temperatures (above 10°C) and colder air temperatures conditions (below 10°C). The results demonstrated clear differences between the both temperature conditions, with the patterns showing a clear a difference in activity throughout the day ( $Z_{\text{Low-temp}} = 2.34 \times 10^{-4}$ ,  $p < 0.05$ ;  $Z_{\text{High-temp}} = 9.32 \times 10^{-4}$ ,  $p < 0.05$ ). In warmer conditions, i.e. milder air temperatures, otter activity patterns remain consistent with their typical patterns; however, the intensity of the late-night activity peak experiences a decline while its duration increases. The species exhibits a bimodal pattern, with two peaks of activity: one at the beginning of the night and the other at the end of the night. When confronted with colder air temperatures, the activity pattern of the otter undergoes a shift, exhibiting also two peaks in its activity cycle, but they are concentrated in the night period. The initial peak occurs at a later in the evening, while the late-night peak exhibits significantly heightened intensity compared to the typical pattern. The activity pattern overlap between these two conditions is low ( $\Delta I = 0.63$ ). However, due to the fact that the Watson-Wheeler test yielded a p-value of 0.453 ( $> 0.05$ ), it was only possible to observe certain trends. This result indicates that, from a statistical perspective, these two groups are equivalent.

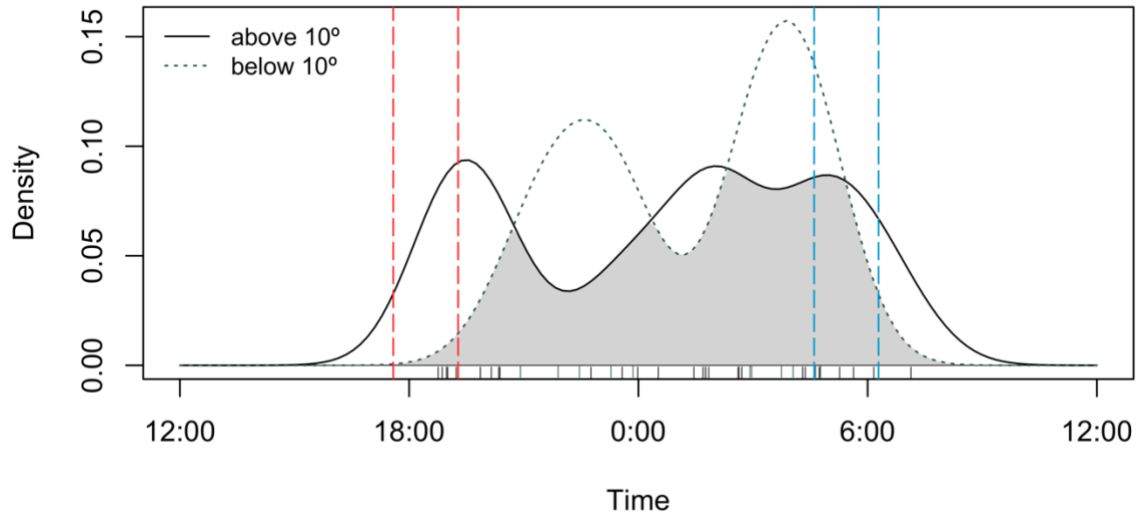


Figure 6. Estimated temporal patterns of *Lutra lutra* in air temperature habitat contexts. Dotted line corresponds to "below 10°" that represents value of air temperatures below 10°C. Straight line corresponds to "above 10°" that corresponds air temperatures superior to 10°C. Vertical dashed red line represents sunrise period values and blue dashed vertical line represents sunset period values. Small vertical lines above x-axis represent various otter records.

#### 4.2.2.3 Human disturbance

The comparison made between areas where the human presence (human presence) was registered and those where no human presence (no human presence) was detected, shows that there are some visual differences between the otter's activity patterns, with a variation of activity along the diary cycle day ( $Z_{\text{No\_human}} = 2.48 \times 10^{-3}$ ,  $p < 0.05$ ;  $Z_{\text{Human}} = 8.99 \times 10^{-5}$ ,  $p < 0.05$ ). However, due to the fact that the Watson-Wheeler test yielded a p-value of 0.916 ( $> 0.05$ ), it was only possible to observe certain trends. This result indicates that, from a statistical perspective, these two groups are equivalent. In areas where human presence was not detected, two typical periods of heightened activity are observed, both of which are notably intense. In the presence of humans, the species activity patterns is accompanied by a marked increase in activity levels throughout the night. The overlap activity pattern coefficient between the two conditions ( $\Delta 1 = 0.80$ ), indicates a high overlap, although demonstrating visible tendencies in their activity pattern.

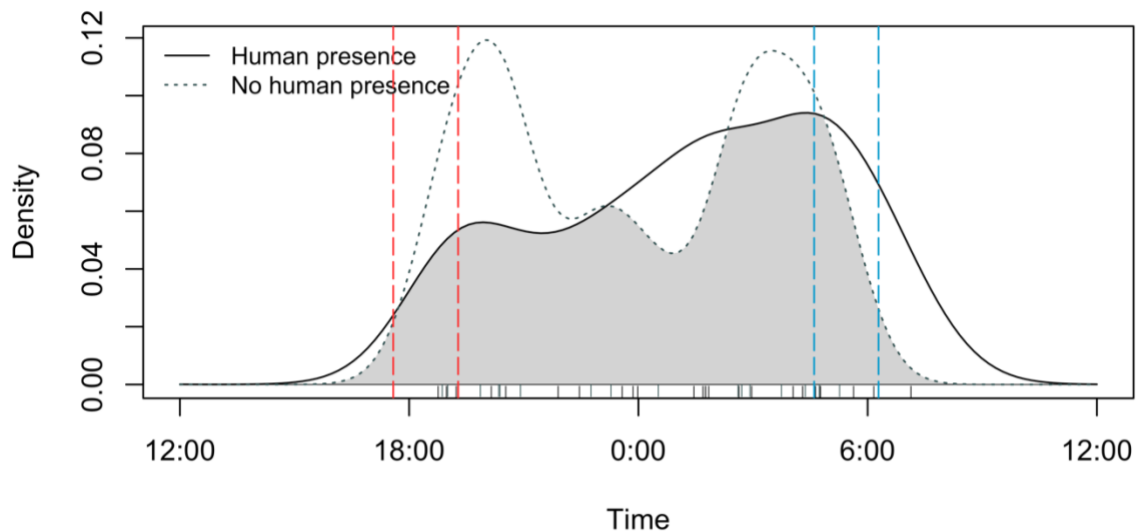


Figure 7. Estimated temporal patterns of *Lutra lutra* in human presence habitat context. Dotted line corresponds to "No human presence" that represents no human presence interference. Straight line corresponds to "Human presence" that corresponds to human presence interference. Vertical dashed red line represents sunrise values and blue dashed vertical line represents sunset. Small vertical lines above x-axis represent various otter records.

### 4.3 *Lutra lutra* spatial patterns

#### 4.3.1 Detectability and occupancy

Two models were identified as the best detectability models, which presented a  $\Delta AICc < 2$ , and consequently, the variables present in these models were selected as influential factors in the detection of the species (Table 6.) The aforementioned variables were "canopy," "depth," and "width." The canopy and stream width variables exhibited a positive relationship with detectability, indicating that as canopy percentage and stream width increased, so did the detectability of the species. The relationship between depth and detectability exhibited a negative correlation, indicating that as the depth of the stream increased, the detectability of otters decreased. With  $AICc=109.9$ , the best model, included only the "canopy" and "width" variables, while in the second model, with an  $AICc=110.6$ , the "depth" variable was also incorporated in conjunction with the two variables already included in the best model. These three variables were subsequently incorporated into all the occupancy models produced in the next modelling phase.

Table 6. Detection probability models ranked by Akaike Information Criterion, corrected for small sample sizes (AICc) and  $\Delta$ AICc, and their degrees of freedom (df), AICc and  $\Delta$ AICc (p – detection probability;  $\Psi$  (1) – constant occupancy probability; Only the first eight models with the higher fit (lower AICc) are presented; Bold models are characterized by  $\Delta$ AICc < 2 (i.e. are the best models).

<b>Model</b>	<b>df</b>	<b>AICc</b>	<b><math>\Delta</math>AICc</b>
<b>p(canopy + width), <math>\Psi</math> (1)</b>	<b>4</b>	<b>109.9</b>	<b>0.00</b>
<b>p(canopy + depth + width), <math>\Psi</math> (1)</b>	<b>5</b>	<b>110.6</b>	<b>0.77</b>
p(canopy + riverbank_height + width), $\Psi$ (1)	5	112.0	2.08
p(canopy + riverbank_heigh + depth + width), $\Psi$ (1)	6	114.1	4.23
p(canopy + depth), $\Psi$ (1)	4	120.9	10.98
p(canopy), $\Psi$ (1)	3	121.2	11.33
p(riverbank_height + width), $\Psi$ (1)	4	122.7	12.84
p(canopy + depth + riverbank_height), $\Psi$ (1)	5	123.4	13.56

Table 7. Estimated regression coefficients for the top-ranked model (lowest AICc) produced to explain otter detectability patterns (Coef – Coefficients; SE – Standard Error; CI 95% - 95% Confidence Interval). The 95% CIs for the coefficients of the predictor variables do not include 0.

<b>Model coefficients</b>	<b>Coef</b>	<b>SE</b>	<b>z</b>	<b>Pvalue</b>
Interception	-3.319	0.764	-4.347	1.38x10 <sup>-5</sup>
Width	1.555	0.621	2.502	1.23x10 <sup>-2</sup>
Depth	-1.184	0.864	-1.371	1.70x10 <sup>-1</sup>
Canopy	1.691	0.876	1.931	5.35x10 <sup>-2</sup>

After identifying the variables that influenced otters' detection, occupancy models were created to determine which variables affect the occupancy of the species in SW Portugal. Those three variables selected in the detection process were subsequently incorporated into all occupancy model produced. From all 4 models we produced, corresponding to the three distinct hypothesis, two models were found to have the lowest AICc values, suggesting that they had the strongest support. The fact that for both the  $\Delta AICc < 2$ , it indicates they can be considered the best models (Table 8), and thus the hypothesis more supported by our data was the one suggesting that *Physical and chemical characteristics of the stream* drivers are those more influencing otters' occupancy. These models included two variables – Depth ("depth"), and Riverbank Height ("riverbank\_height") (Table 9). The variable associated with riverbank height exhibited a positive coefficient, indicating a tendency for otter occupancy to increase as riverbank height increases as well. The stream depth variable exhibits a negative coefficient, suggesting a trend whereby increased depth is associated with reduced otter occupancy. However, all these variables 95% confidence intervals of their coefficients included the zero. This indicates a considerable degree of uncertainty regarding the influence of these variables. However, we can induce the observed trend in their effect as most of the interval is negative. The goodness-of-fit of the model shows that there is no evidence for a lack of fit of the model (MacKenzie and Bailey goodness-of-fit  $\chi^2=261.0117$ ,  $p=0.444$ ), nor for data overdispersion ( $c\text{-hat} = 1.01$ ).

Table 8.  $\Delta AICc < 2$  occupancy models per hypothesis H1-H4. The model best supported by our data (i.e., Overall  $\Delta AICc = 0$ ) are in bold; p – detection probability;  $\Psi$  – occupancy probability; df -degrees of freedom; AICc- Akaike's Information Criterion corrected for small sample sizes;  $\Delta AICc$  – the difference in AICc between the top model within each hypothesis and the top model in that hypothesis; Overall  $\Delta AICc$  - the difference in AICc between the top model within each hypothesis and the top overall model.

Model	df	AICc	Overall $\Delta AICc$
<i>H1- Physical and chemical characteristics of the stream</i>			
<b>p(canopy + depth + width), <math>\Psi</math> (depth + riverbank_height)</b>	<b>6</b>	<b>102.3</b>	<b>0.0</b>
<i>H4-Variables combined model</i>			
<b>p(canopy + depth + width), <math>\Psi</math> (depth)</b>	<b>7</b>	<b>103.1</b>	<b>0.8</b>
<i>H1- Physical and chemical characteristics of the stream</i>			
p(canopy depth + width), $\Psi$ (1)	4	104.4	2.1
<i>H3- Human presence</i>			
p(canopy + depth + width), $\Psi$ (1)	6	104.5	2.2
<i>H2- Vegetation</i>			
p(canopy + depth + width), $\Psi$ (1)	5	104.5	2.2

Table 9. Estimated regression coefficients for the average models with  $\Delta AICc < 2$ , produced to explain Lutra lutra occupancy patterns (Coef – Coefficients; SE – Standard Error; CI 95% – 95% Confidence Interval). The 95% CIs for the coefficients of the predictor variables include 0.

Model coefficients	Coef	SE	CI 95%	Pvalue
Interception	13.441	20.715	-20.362 47.514	0.516
Depth	-28.869	35.755	-87.349 29.610	0.416
Riverbank Height	35.345	41.032	-32.139 109.814	0.388

### 4.3.2 Detectability and abundance

Three models were developed to ascertain which variables influenced otter detectability when considering species abundance. Of these models, three were identified as the most suitable (i.e.,  $\Delta AICc < 2$ ; Table 10). The findings of the analysis suggested that, among the variables evaluated, canopy cover, stream width, and riverbank height emerged as the primary factors contributing to detectability. The relationship between canopy cover, stream width and riverbank height, and the probability of detection is positive; that is, the greater the canopy cover, stream width and riverbank height, the higher the probability of detection. A negative relationship has been observed between stream depth and probability of detection, i.e., as the depth of the stream increases, the likelihood of detection decreases.

Table 10. Detection probability models ranked by Akaike Information Criterion, corrected for small sample sizes (AICc) and  $\Delta AICc$  and their degrees of freedom (df), AICc and  $\Delta AICc$  (p – detection probability;  $\lambda(1)$  – constant occupancy probability; Only the first eight models with the higher fit (lower AICc) are presented; Models highlighted in bold are characterized by  $\Delta AICc < 2$  (i.e. are the best models).

Model	df	AICc	$\Delta AICc$
<b>p(canopy + depth + riverbank_height + width), <math>\lambda(1)</math></b>	<b>6</b>	<b>203.3</b>	<b>0.00</b>
<b>p(canopy + depth + width), <math>\lambda(1)</math></b>	<b>5</b>	<b>204.6</b>	<b>1.32</b>
<b>p(canopy + width), <math>\lambda(1)</math></b>	<b>4</b>	<b>205.0</b>	<b>1.75</b>
p(canopy + riverbank_height + width), $\lambda(1)$	5	206.4	3.11
p(canopy + riverbank_height), $\lambda(1)$	4	208.2	4.93
p(canopy), $\lambda(1)$	3	208.7	5.45
p(canopy + depth + riverbank_height), $\lambda(1)$	5	211.0	7.67
p(canopy + depth), $\lambda(1)$	4	211.7	8.40

Table 11. Estimated regression coefficients for the top-ranked model (lowest AICc) produced to explain otter detectability patterns (Coef – Coefficients; SE – Standard Error; CI 95% □ 95% Confidence Interval). The 95% CIs for the coefficients of the predictor variables do not include 0.

Model coefficients	Coef	SE	z	Pvalue
Interception	-6.080	1.473	-4.13	3.65x10 <sup>-5</sup>
Width	0.921	0.272	3.38	7.20x10 <sup>-4</sup>
Depth	-1.380	0.557	-2.48	1.33x10 <sup>-2</sup>
Canopy	3.114	0.748	4.16	3.15x10 <sup>-5</sup>
Riverbank Heigth	1.322	0.576	2.30	2.17x10 <sup>-2</sup>

Four models were constructed for the three working hypotheses (i.e., the Physical and chemical characteristics of the stream, Vegetation, Human presence and Variables combined). The results indicated that for the the first two hypotheses ("*Physical and Chemical characteristics of the stream*" and "*Vegetation*") only one variable was included on best model for abundance: “riverbank height” and “logs”, respectively. In what concerns the "*Human presence*" hypothesis, no variable was found to be selected, as the null model was the best model explaining otters’ abundance variation. A final model was created with the variables selected by the  $\Delta AICc < 2$  method from the other three hypotheses (H1, H2, H3), incorporating two variables (logs and riverbank height), as they were included in the best models of each hypothesis, and the 95% confidence intervals did not include the zero. However, a comparative analysis of all produced models (Table 12.), ranked by the overall  $\Delta AICc$ , reveals that the best overall model (i.e. overall  $\Delta AICc = 0$  an  $AICc = 195.6$ ), is the best model of the "*Vegetation*" hypothesis. It included only the variable "Logs" as the most influential driver of otter abundance. This variable exhibits a positive coefficient, suggesting a direct and positive influence on otter population abundance (Table 13.). This indicates that otter populations tend to be more abundant in areas with a presence of fallen logs within the stream. The 95% confidence interval is strictly positive and does not intersect with zero, thereby reinforcing the observed positive cant effect, corroborated by the significance of the statistical test (z-score= 3.178; p-value =  $7.04 \times 10^{-3}$ ). The goodness-of-fit results ( $\chi^2=162.9829$ ; P-value = 0.236) indicate a good fit on this best models, and there is no evidence of overdispersion of residuals (  $\hat{c} = 1.1$ ).

Table 12.  $\Delta AICc < 2$  occupancy models per hypothesis H1-H4. The model best supported by our data (i.e., Overall  $\Delta AICc = 0$ ) are in bold; p – detection probability;  $\Psi$  – occupancy probability; df -degrees of freedom; AICc- Akaike’s Information Criterion corrected for small sample sizes;  $\Delta AICc$  – the difference in AICc between the top model within each hypothesis and the top model in that hypothesis; Overall  $\Delta AICc$  - the difference in AICc between the top model within each hypothesis and the top overall model.

<b>Model</b>	<b>df</b>	<b>AICc</b>	<b>Overall <math>\Delta AICc</math></b>
<i>H2- Vegetation</i>			
<b>p(canopy + depth + width + riverbank_height), <math>\lambda</math> (logs)</b>	<b>6</b>	<b>195.6</b>	<b>0.0</b>
<i>H4- Variables combined model</i>			
p(canopy + depth + width+ riverbank_height), $\lambda$ (logs)	7	197.3	1.7
<i>H1- Physical and chemical characteristics of the stream</i>			
p(canopy + depth + width + riverbank_height), $\lambda$ (riverbank_height)	6	203.3	7.7
<i>H3- Human presence</i>			
p(canopy + depth + width + riverbank_height), $\lambda$ (1)	5	204.6	9.0
<i>H1- Physical and chemical characteristics of the stream</i>			
p(canopy + depth + width + riverbank_height), $\lambda$ (1)	5	204.6	9.0
<i>H1- Physical and chemical characteristics of the stream</i>			
p(canopy + depth + width + riverbank_height), $\lambda$ (1)	6	204.6	9.0

Table 13. Estimated regression coefficients for the top-ranked model (lowest overall AICc) produced to explain *Lutra lutra* abundance patterns (Coef – Coefficients; SE – Standard Error; CI 95% – 95% Confidence Interval). The 95% CIs for the coefficients of the predictor variables include 0. Variable in bold is statistically significant, p-value < 0.05

<b>Model coefficients</b>	<b>Coef</b>	<b>SE</b>	<b>z</b>	<b>CI 95%</b>		<b>Pvalue</b>
<b>Interception</b>	<b>1.827</b>	<b>1.256</b>	<b>1.454</b>	<b>-0.239</b>	<b>3.894</b>	<b>1.48×10<sup>-2</sup></b>
<b>Logs - presence</b>	<b>1.939</b>	<b>0.610</b>	<b>3.178</b>	<b>0.935</b>	<b>2.942</b>	<b>7.04×10<sup>-3***</sup></b>

## 5. Discussion

The main findings can be categorized into two distinct domains: activity patterns and spatial patterns. With regard to activity patterns, otters have been observed to exhibit a strictly nocturnal activity pattern with a crepuscular tendency, indicating a bimodal distribution of activity times. In relation to the species' activity patterns in response to divergent environmental conditions, it was found that, although there was no significant response to it, some trends were observed. In periods of enhanced moonlight, the otter exhibited a transition from a bimodal activity pattern, characterized by a bimodal tendency, to a unimodal activity pattern during the middle of the night. In periods of elevated temperature, the otter exhibited heightened activity, manifesting more pronounced peaks in its movement patterns. In the presence of humans, the otter exhibited elevated levels of activity throughout the night, thereby demonstrating a shift from a bimodal to a more continuous activity pattern. Regarding spatial patterns, the occupancy models demonstrated that the variable that best explains otter occupancy is stream depth, although this variable was not statistically significant. Conversely, the abundance models indicated that the presence of logs in the stream is the most significant factor in explaining the observed otter population, and this finding is statistically significant.

### 5.1 Global activity pattern

Overall, otters inhabiting riparian ecosystems of southwestern Europe showed a non-uniform activity pattern throughout the circadian cycle, with the nocturnal hours corresponding to the period with the greatest activity frequency (with a two activity peaks, one at the sunset and another at sunrise). This pattern aligns with our initial predictions, and may be due to several factors. According to the research by Hung & Law (2016), this species is not subject to natural predation in the designated study area. This ecological characteristic enables the species to exhibit high levels of activity during periods of optimal conditions, unencumbered by constraints imposed by predators. Furthermore, in this region of Portugal, the species faces no competition, a factor that allows it to select the most optimal periods to be active and thus optimize predation success. When competition is strong, temporal mismatches are often a strategy to reduce competition and promote coexistence (Ferreiro-Arias et al., 2020). Otter populations inhabiting southwestern Portugal prey mostly on crayfish *Procambarus clarkii* (Matos H., 1999; (Pedroso & Santos-Reis, 2023), and this nocturnal activity allow otter to strong overlap their hunting periods with those of their prey. *Procambarus clarkii* is particularly active during the nocturnal period (Gherardi et al., 2000), which increases otters hunting success . During the day the crayfish remain hidden under rocks and other structures that are underwater, and at night they are found outside these structures, facilitating their detection and capture by otters. Freshwater fish are also a common prey item of the otter (Pedroso & Santos-Reis, 2023), exhibiting higher activity levels during the day (Carlander & Cleary, 1949), however, their reduced mobility during the night makes them more vulnerable to being hunted by the otter, thereby increasing the otter's prey capture success rate (Emery, 1973). Finally, avoiding being active during the day also allows them to avoid direct human disturbance or persecution (Teixeira et al., 2023; Bolas et al., 2025), as they start their activity just after sunset and end it before sunrise. The two activity peaks (after sunset and before sunrise) could be linked to the need to look for food just after their inactive period (daytime) and before retrieving to their dens, to fulfill their energetic need after and before a period without feeding, respectively.

## 5.2 Activity patterns in different environmental conditions

These overall nocturnal activity patterns varied with the environmental conditions, although the species always show a non-uniform circadian activity concentrated the active hours in the night period. The three tested conditions (moon phase, air temperature, and human disturbance) revealed some influence on otters' activity patterns. These results suggest that otters may exhibit tendencies to have different behaviors depending on specific environmental conditions, over a 24-hour period. However, due to the absence of a statistical significant difference ( $p\text{-value} < 0.05$ ) for any of the tested conditions (Watson-Wheeler's test), we must be careful in interpreting some mismatch in activity patterns we detected. Thus, drawing definitive conclusions regarding the differences that may exist between the activity patterns in the different conditions considered must be done with caution. Therefore, it is only possible to discuss the possible trends that may be exhibited by otters, especially because the available data set comprises solely 41 otter detections.

### 5.2.1 Moon phase

As Krisciunas and Schaefer (1991) have demonstrated, the quantity of luminosity during nocturnal periods is subject to considerable variation, contingent upon the distinct lunar phases. Although otters are always nocturnal, during nocturnal periods when the light levels decrease in intensity (low to half), otters exhibit a shift in their typical activity patterns, concentrating their activity in the middle of the night. Species that have a greater probability of being active at night are usually more likely to be more active also at new moon (Bischof et al. 2024). This phenomenon may be attributed to otters' strategic exploitation of nocturnal periods with reduced light intensity to enhance their hunting success. Pugh and Golden's (2013) study demonstrated that the probability of hunting is positively influenced by the absence of moonlight, given that predators remain undetected. It can also be said that otters reduce their activity by shifting from two peaks of activity to just one. This may be a strategy to reduce their activity when light conditions are unfavorable (Sordello et al., 2025). One adaptation of *Lutra lutra* is its reliance on sensitive whiskers (vibrissae), which enable it to detect vibrations and hunt more effectively in low-visibility conditions (Grant & Goss, 2021; Grant, 2026).

### 5.2.2 Air temperature

Otters' activity also shows some variation according to the air temperature, with activity peaks being more intense in cold temperatures ( $< 10^{\circ}\text{C}$ ). This suggests that there is a higher proportion of active individuals during these periods. This phenomenon may be indicative of otters' propensity to concentrate on their activity in shorter periods where the levels of activity are heightened. In these low temperature periods otters may choose to be active in shorter but concentrated periods, which could be an adaptation to the colder temperature of the water, which causes otters to lose heat more rapidly. Thus, this phenomenon may be an adaptation to overcome temporary temperature (Kruuk et al., 1997) and energy loss (Oleynikov, 2009). Conversely, as environmental temperatures decrease, individuals must allocate more energy to generate heat. In addition to the heightened intensity of the peaks, the activity pattern during the 24-hour period is also reduced in duration when temperatures are lower, due to the same

underlying mechanism. Notwithstanding this observation, otters persist in exhibiting bimodal activity patterns, suggesting that this behavior may be a typical pattern of otters.

### **5.2.3 Human disturbance**

Our study findings indicate that in the absence of human presence, the temporal pattern exhibits minimal deviation from the general pattern characteristic of the species, maintaining a more uniform night activity pattern in areas where humans are more present. In areas where humans are not present otters evidence a bimodal activity pattern, indicating the persistence of crepuscular activity, suggesting that the species does not feel compelled to modify its behaviors in in such context. However, it is widely recognized that mammals exhibit significant responses to direct human presence, which compels them to modify their behaviors (Procko et al., 2023). For example, the presence of humans has been shown to induce a discernible alteration in the temporal pattern, with many mammal species becoming more nocturnal (Gaynor et al., 2018). Otters show a somewhat similar pattern with activity concentrated in the night period, peaking around 5 a.m., and then rapidly decreasing, when the onset of morning human activities occur. This can demonstrate, that possibly, human disturbance can have an influence on this species temporal patterns.

## **5.3 Drivers of otters' spatial patterns**

*Lutra lutra* is a mesocarnivores highly dependent on rivers for survival (Macdonald & Mason, 1983), and therefore understanding what characteristics of Mediterranean riparian systems influence the use and abundance of this ecosystem is crucial to make decisions regarding the management and protection of the species.

### **5.3.1 Occupancy**

Occupancy models play a pivotal role in the study of species distribution patterns (Stewart et al., 2022), particularly in scenarios where detection is imperfect (Benoit et al., 2018). Therefore, the initial step is to ascertain which variables are affecting otter detection. The detectability of the species was influenced by three variables: stream depth, width, and canopy cover. The stream depth appeared to have a negative influence on the species detectability, which may indicate that the greater the stream depth, the more likely the otter is to submerge and thus not be detected by the camera. The stream width exhibited a positive influence, indicating that an increase in width resulted in greater detectability. This pattern may be linked to the fact that an increase in stream width, and consequently surface area, provides otter with more space to traverse the water body. This, in turn, results in an enhanced detection window for the camera, leading to increased detection rates. Canopy cover exhibits a positive relationship, whereby an increase in tree canopy cover results in an increase in species detectability. The denser the canopy, the more it obstructs the light reaching the stream (e.g., moon light) and the more protected from disturbance it is. This more stable environment will promote detectability by reducing variations that could affect the ability of the camera to detect otters. A thorough examination of the results yielded by the occupancy models reveals that both hypotheses, *H1- Physical and chemical characteristics of the stream* and *H4- Variables combined model* (exhibitin an AICc = 102.3 and AICc = 103.1, respectively), generated

models with an overall  $\Delta\text{AICc} < 2$ . Consequently, these models are considered the most suitable to explain otter's occupancy variation. Nevertheless, the model included in *H1- Physical and chemical characteristics of the stream* was identified as the most optimal due to its lowest AICc value. This model included the variables stream depth, vegetation cover and logs presence. However, upon rigorous analysis of these variables, it was determined that none of them were statistically important (i.e.  $P > 0.05$  and the 95% confidence intervals of their coefficient included the 0). Nonetheless, it is possible to highlight certain trends. A notable observation is the negative coefficient associated with depth, which could imply that shallower depths may be more conducive to otter occupation. This phenomenon may be attributed to the nature of the streams that were sampled; wherein shallower streams might be more conducive to otters feeding. As demonstrated by Kruuk and Moorhouse (1990), the species *Lutra lutra* exhibits a marked preference for shallow waters, a preference that has been shown to increase its hunting productivity. With regard to the elevation of the riverbank, a positive coefficient was observed, suggesting that the area under consideration exhibits a greater degree of occupation at higher elevations. This outcome is not consistent with our initial expectations, which anticipated a negative relationship.

### 5.3.2 Abundance

According to the produced N-mixture models the detectability of otters was influenced by four variables: stream width, depth, canopy cover, and riverbank height. The mechanism linked to the effect of the first three variables on otters' detectability were already explained in the occupancy models' section. Riverbank height showed a positive influence on otters detectability, because the higher the riverbank, the greater the angle and field of view captured by the camera. And therefore, a higher probability of detecting an individual. It is hypothesized that the remaining three variables are associated with the factors identified in the occupancy models, which will be reiterated. The depth of the environment appeared to exert a negative influence on the species, which may indicate that the greater the depth, the more likely the otter is to submerge and thus not be detected by the camera. The width exhibited a positive influence, indicating that an increase in width resulted in greater detectability. The correlation between stream width and otter detectability can be attributed to the aforementioned phenomenon. It has been demonstrated that an increase in stream width—and, consequently, surface area—affords otters a greater expanse for traversing a given water body. This, in turn, results in enhanced visibility for the camera, leading to increased detection rates. The relationship between canopy density and species detection is positive; that is, an increase in tree canopy results in an increase in species detection. This phenomenon can be attributed to the physical characteristics of the plant, specifically the size of its canopy. The extent of the canopy's coverage is directly proportional to its impact on moon light transmission to the stream, leading to a corresponding reduction in visibility for detecting individuals due to light reflexion. Regarding the drivers of otters' abundance, the hypothesis that demonstrated the strongest support from the data was *H2 - Vegetation*, which exhibited an  $\text{AICc}=195.6$ . This model shows that the variable presence of logs is the most influential in shaping the species abundance. The presence of logs in the stream has a positive correlation with the abundance of otters. As this variable showed a CI 95% of its coefficient with only positive values and never crosses zero, and its effect was statistically significant (i.e.  $p < 0.05$ ), we can assume it is an informative driver (Arnold, 2010). The presence of these structures in otters' habitats can be explained by the functional benefits they provide to otters. These benefits include enhanced hunting capabilities, as the structures offer otters advantageous locations from which to observe and attack their prey. This phenomenon has been demonstrated to result in otters engaging in more efficient hunting, leading to a subsequent reduction in energy expenditure given the

decreased time spent submerged (MacArthur & Dyck, 1990; Carss D., 1995). Play, utilization as a passageway across the stream (Fumagalli, 1995), and resting spots (Madsen & Prang, 2001), are also some of the benefits of these structures, as these are ideal conditions for increasing otter abundance. It is also conceivable that the species may utilise these structures due to the fact that these can provide shelter for its prey (Pretty et al., 2003). Consequently, these structures have been linked to the availability of food sources, thus providing a selective advantage in the context of hunting. However, there is a lack of studies that definitively demonstrate that the presence of fallen logs in the stream exerts a substantial influence on this species, which may indicate a local adaptation to these conditions.

## **6. Limitations**

During this study, a number of issues were identified in the sampling and subsequent data analysis processes, that could affect results obtained and consequently the observed patterns. During the sampling process, the positioning of the cameras presented a significant challenge due to the topography of the terrain in which the streams were situated (e.g., stream margin steepness). In certain instances, it is not feasible to position the camera at the originally intended location due to the inaccessibility of these areas. Consequently, adhering to the prescribed distance of 500 meters becomes a challenging endeavor. Given that the streams are considered public property, they are of free access to the general population, and to the landowners of the contiguous farms. Consequently, the potential for damage or theft to our camera-traps was a recurrent concern, that this particular issue manifested itself during the process of sampling. In the Winter period (i.e. initial months of 2025), Portugal experienced a period of intense rainfall, leading to substantial increases in stream flow. This phenomenon may have affected the robustness of our data collection. Coincidentally no otter records were made during this time, as well as from any other carnivore species. Furthermore, during the data analysis process, a major issue was identified that restricted our ability to explore further our dataset. That issue is related due the fact that there were only 41 independent otter records, which is a low number of records that can limit the power of our models. Nevertheless, the presented data includes a new data on otter spatial and temporal ecological patterns for Portugal, which enhance its importance to help us understand this mesocarnivores adaptation to changing environment. It is important to note that otters are known to traverse the stream within the water body, which has the potential to result in a reduction of detectability by the cameras. This, in turn, can lead to a decrease in the number of detections. Nonetheless, this bias is analogous across all cameras. Consequently, while it may impact the number of records, it is believed to have no effect on the overall patterns detected.

## **7. Conservation implications and future reaserch**

The unique environmental and anthropogenic characteristics of the Mediterranean region have been identified by numerous studies (Giorgi & Lionello, 2007), and are significantly different from other regions, particularly in riparian systems, which are often characterized by an intermittent regime (Vila-Gispert et al., 2005). Consequently, studies of this nature are imperative to comprehend the drivers that determined the spatial and temporal ecology patterns of otters within this distinctive climate and environment. Notwithstanding the thriving otter population in Portugal, as evidenced by the favorable conservation situation (Pedroso & Santos-Reis, 2023), the species may still be susceptible to the impacts

of climate change, that several studies show will be acute in southern Europe (Prenda et al., 2001; Cianfrani et al., 2011). Consequently, a comprehensive understanding of the temporal and spatial dynamics of this species, and what might be determining their response to the different contexts of mediterranean riparian ecosystems is imperative to mitigate possible declines in specific regions of its distribution due to environmental changes. The present study demonstrated that certain variables, including the presence of logs within streams, with the associated conditions they create, have the capacity to promote species abundance. Consequently, the clearance of vegetation in riparian ecosystems, both within the riparian galleries and in the surrounding areas, should be carefully considered and, whenever possible, minimized or suspended. When it is not possible to maintain logs within streams, alternative measures, should also be taken, as the construction of artificial structures to enhance the stream complexity and create conditions that may allow to otter population growth/recover in regions where populations experience challenges related to streams environmental degradation. It is also recommended that further studies of this nature should be conducted on a broader scale in order to assess if the detected local patterns are also common to other populations and enhance our understanding of how otters respond to variations of local environmental conditions. This will contribute to the a more informed decisions regarding the conservation of the species.

## **8. Conclusion**

This study highlight the behavioral patterns exhibited by otters under varied environmental contexts, linked to both the temporal and spatial dimension of it niche. Otters exhibit a predominantly nocturnal activity pattern with crupuscular tendency (Kruuk, 2006.), like it was already described in the Mediterranean region (Quaglietta et al., 2012), The otter's temporal response to the variation in moonlight, temperature and human disturbance conditions, it remains unclear whether these factors exert an important influence on the species. At the spatial level, it is evident that vegetation seems to be the most important determinant of otters's occupancy and abundance patterns. A positive correlation was identified between the presence of logs and otter abundance. This finding suggests that the otters are utilizing the area in a beneficial manner, as the presence of logs may offer suitable resting places. As demonstrated by Madsen & Prang (2001), river crossings are facilitated (Fumagalli, 1995), and hunting efficiency is enhanced (MacArthur & Dyck, 1990; Carss D., 1995).

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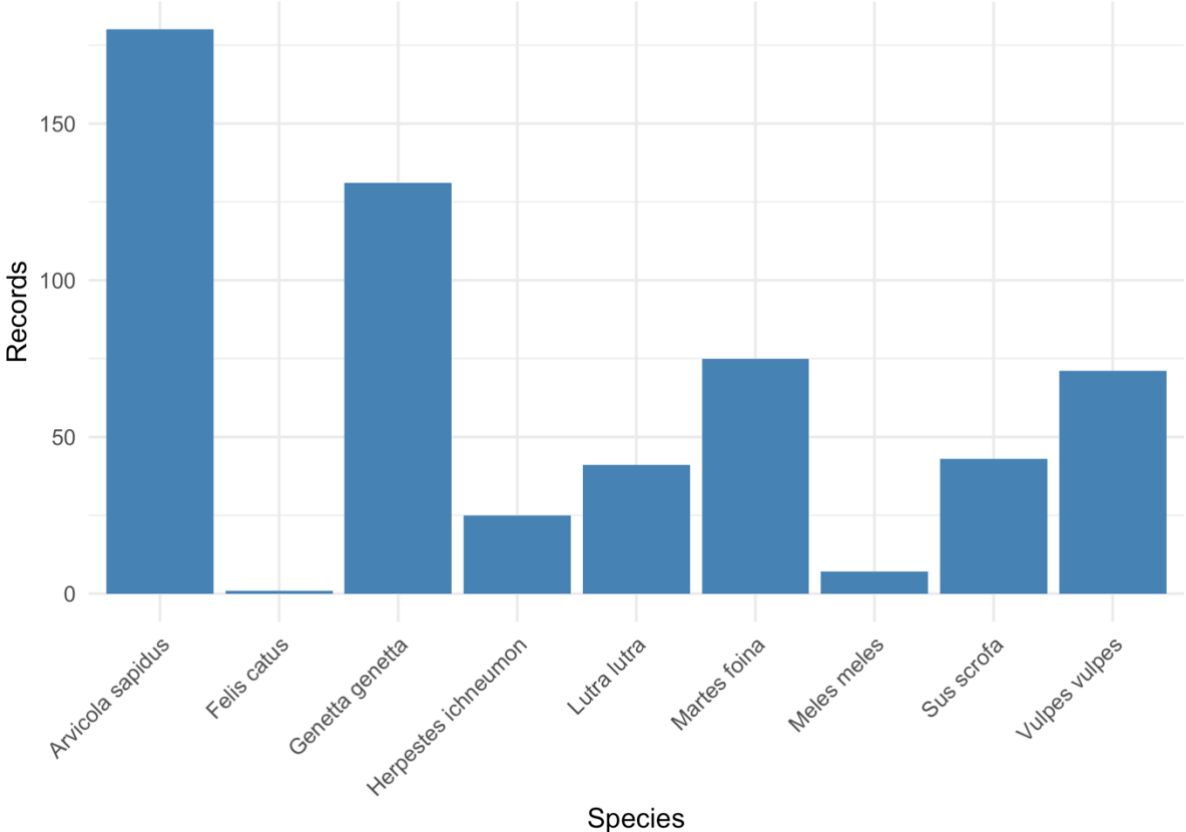
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**Appendices**



Number of records per species.

Detection probability models ranked by AICc and  $\Delta$ AICc and their degrees of freedom (df), AICc and  $\Delta$ AICc (p – detection probability;  $\Psi$  (1) – constant occupancy probability; Only the first eight models with the higher fit (lower AICc) are presented; Bold models are characterized by  $\Delta$ AICc < 2.

<b>psi(Int)</b>	<b>p(Int)</b>	<b>p(canopy)</b>	<b>p(depth)</b>	<b>p(riverbank_height)</b>	<b>p(width)</b>	<b>df</b>	<b>logLik</b>	<b>AICc</b>	<b>delta</b>	<b>weight</b>
<b>1.352</b>	<b>-3.639</b>	<b>3.59</b>			<b>1.666</b>	<b>4</b>	<b>-49.828</b>	<b>109.879</b>	<b>0</b>	<b>0.461</b>
<b>2.099</b>	<b>-3.575</b>	<b>2.981</b>	<b>-1.651</b>		<b>2.103</b>	<b>5</b>	<b>-48.558</b>	<b>110.646</b>	<b>0.767</b>	<b>0.314</b>
1.502	-3.886	2.906		-1.673	1.88	5	-49.216	111.961	2.082	0.163
2.27	-3.685	2.663	-1.433	-0.838	2.132	6	-48.431	114.112	4.233	0.056
0.511	-1.991	2.197	1.532			4	-55.32	120.863	10.984	0.002
0.819	-2.076	1.65				3	-56.973	121.21	11.331	0.002
0.362	-2.798			-4.443	1.365	4	-56.247	122.717	12.838	0.001
0.558	-2.286	2.025	2.189	-1.209		5	-54.952	123.434	13.555	0.001
0.83	-2.085	1.635		-0.04		4	-56.972	124.167	14.288	0
0.718	-2.857		-1.099	-3.881	1.676	5	-55.46	124.45	14.571	0
0.184	-2.08		3.297	-4.939		4	-57.299	124.82	14.941	0
-0.081	-1.183			-1.258		3	-60.347	127.957	18.078	0
0.137	-1.241		-2.514		0.991	4	-59.317	128.857	18.978	0
-0.397	-0.553					2	-62.801	130.203	20.324	0
-0.256	-0.749		-0.718			3	-61.882	131.027	21.148	0
-0.403	-0.526				-0.116	3	-62.594	132.451	22.572	0

Top model H4-Variables combines model. Bold models are the one with  $\Delta AICc < 2$ . Variables with a  $\Delta AICc < 2$  are “veg\_cover” and “logs”.

<b>psi(Int)</b>	<b>psi(depth)</b>	<b>psi(logs)</b>	<b>psi(veg_cover)</b>	<b>p(Int)</b>	<b>p(canopy)</b>	<b>p(depth)</b>	<b>p(width)</b>	<b>df</b>	<b>logLik</b>	<b>AICc</b>	<b>delta</b>	<b>weight</b>
<b>117.185</b>	<b>211.922</b>		<b>-38.28</b>	<b>-2.67</b>	<b>1.167</b>	<b>-2.28</b>	<b>1.436</b>	<b>7</b>	<b>-40.778</b>	<b>103.023</b>	<b>0</b>	<b>0.333</b>
<b>102.177</b>	<b>156.314</b>			<b>-2.795</b>	<b>1.189</b>	<b>-2.141</b>	<b>1.413</b>	<b>6</b>	<b>-42.936</b>	<b>103.123</b>	<b>0.1</b>	<b>0.317</b>
<b>1.909</b>				<b>-3.2</b>	<b>2.058</b>	<b>-1.371</b>	<b>1.551</b>	<b>5</b>	<b>-45.473</b>	<b>104.475</b>	<b>1.452</b>	<b>0.161</b>
0.349		+		-2.939	2.004	-1.192	1.404	6	-44.034	105.319	2.296	0.106
1.899			0.07	-3.198	2.06	-1.362	1.548	6	-45.472	108.194	5.171	0.025
0.107		+	-1.556	-2.951	1.888	-1.461	1.466	7	-43.408	108.283	5.26	0.024
9.938	34.489	+	-18.672	-2.993	1.742	-1.898	1.585	8	-41.27	108.826	5.803	0.018
0.66	1.162	+		-2.962	1.903	-1.498	1.487	7	-43.777	109.021	5.998	0.017

Detection probability models ranked by AICc and  $\Delta$ AICc and their degrees of freedom (df), AICc and  $\Delta$ AICc (p – detection probability;  $\lambda$  (1) – constant occupancy probability; Only the first eight models with the higher fit (lower AICc) are presented; Bold models are characterized by  $\Delta$ AICc < 2.

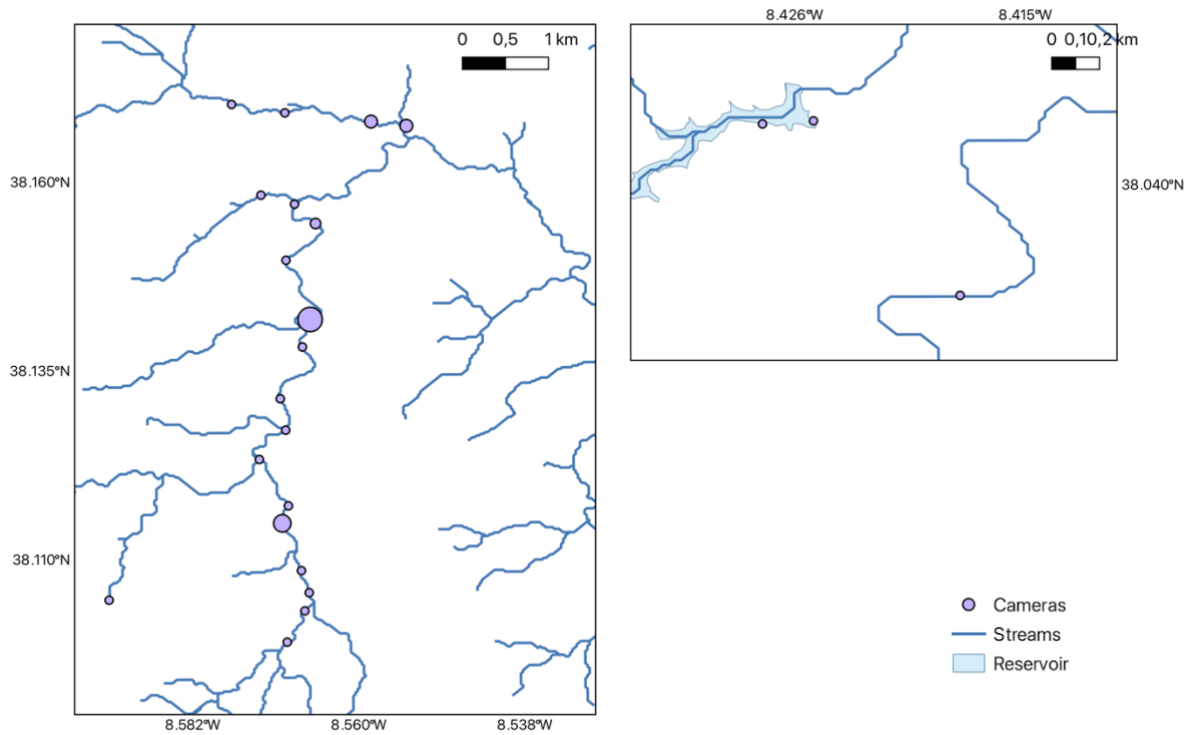
<b>lam(Int)</b>	<b>p(Int)</b>	<b>p(canopy)</b>	<b>p(depth)</b>	<b>p(riverbank_height)</b>	<b>p(width)</b>	<b>df</b>	<b>logLik</b>	<b>AICc</b>	<b>deltaAICc</b>	<b>weight</b>
<b>2.873</b>	<b>-6.08</b>	<b>3.114</b>	<b>-1.38</b>	<b>1.322</b>	<b>0.921</b>	<b>6</b>	<b>-93.023</b>	<b>203.295</b>	<b>0</b>	<b>0.429</b>
<b>2.426</b>	<b>-5.181</b>	<b>2.127</b>	<b>-0.852</b>		<b>0.859</b>	<b>5</b>	<b>-95.544</b>	<b>204.618</b>	<b>1.323</b>	<b>0.221</b>
<b>1.822</b>	<b>-4.705</b>	<b>2.48</b>			<b>0.571</b>	<b>4</b>	<b>-97.413</b>	<b>205.049</b>	<b>1.754</b>	<b>0.179</b>
1.797	-4.945	3.129		0.725	0.507	5	-96.438	206.406	3.111	0.091
1.638	-4.281	2.58		0.794		4	-99.001	208.223	4.928	0.037
1.616	-3.996	1.891				3	-100.741	208.745	5.45	0.028
1.912	-4.452	2.395	-0.36	0.876		5	-98.718	210.966	7.671	0.009
1.64	-4.008	1.867	-0.035			4	-100.738	211.698	8.403	0.006
0.548	-1.895		-1.76		0.66	4	-112.283	234.789	31.494	0
0.511	-1.85			-0.694		3	-114.148	235.559	32.264	0
0.443	-1.658		-0.798			3	-114.654	236.571	33.276	0
0.611	-2.065			-0.981	0.266	4	-113.481	237.183	33.888	0
0.319	-1.452					2	-116.546	237.693	34.398	0
0.729	-2.268		-0.845	-0.82	0.583	5	-112.236	238.002	34.707	0
0.518	-1.859		-0.04	-0.673		4	-114.147	238.517	35.222	0
0.306	-1.428				-0.077	3	-116.443	240.149	36.853	0

Top model H4-Variables combines model. Bold model is the one with  $\Delta AICc < 2$ . Variable with a  $\Delta AICc < 2$  is “Logs”.

<b>lam(Int)</b>	<b>lam(canopy)</b>	<b>lam(logs)</b>	<b>lam(veg_cover)</b>	<b>p(Int)</b>	<b>p(canopy)</b>	<b>p(depth)</b>	<b>p(width)</b>	<b>df</b>	<b>logLik</b>	<b>AICc</b>	<b>delta</b>	<b>weight</b>
<b>1.580</b>		+		<b>-5.278</b>	<b>1.676</b>	<b>-0.448</b>	<b>0.485</b>	<b>6</b>	<b>-89.174</b>	<b>195.59</b>	<b>0</b>	<b>0.689</b>
1.768		+	-0.328	-5.540	1.484	-0.295	0.379	7	-88.345	198.15	2.557	0.191
1.852	-0.472	+		-5.560	2.169	-0.449	0.486	7	-89.097	199.66	4.060	0.090
1.827	-0.504	+	-0.328	-5.618	2.020	-0.296	0.382	8	-88.284	202.85	7.254	0.018



Representation of “Logs” structures that positively affect otter abundance.



Study area and cameras represented in Alentejo, Setubal district, Portugal. The upper square is located in Northern Serra de Grândola, near Grândola city, where 20 camera traps were set. The lower square is located in Lousal (south of Grândola), where 3 camera traps were installed. Size corresponds the number of detections.