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THE APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN THE DEVELOPMENT OF A SUITABILITY INDEX FOR PROSPECTING TETRAPOD FOSSILS IN THE MUNICIPALITY OF LOURINHÃ

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ABSTRACT

Paleontological prospection campaigns are traditionally planned around previous knowledge of sites that have provided fossils and the interpretation of the regional geology. The application of a suitability index developed for the study of other rock formations (e.g. Two Medicine Formation, in Canada and USA) in the Upper Jurassic deposits of the Lourinhã municipality (Portugal), we determined areas with a higher likelihood of providing tetrapod fossils. The index was built using geospatial data, and through the usage of a weighted sum it was possible to determine the values of the suitability index, and then project them unto a map of the municipality of Lourinhã. The total area of the municipality was divided according to different suitability indexes: lower (overall area of 29,55 km^2), medium (overall area of 78,56 km^2) and higher (overall area of 39 km^2). The application of these methods allows considering distinct factors beyond the geology that can speed up the decision-making process for prospecting and land management.

Keywords: Territorial planning, Dinosaurs, Lusitanian Basin, Upper Jurassic.

1. INTRODUCTION

ArcGIS® Pro is a software widely used for spatial data analysis and visualization. This software can be used to develop suitability indexes, as described by Wayne (2003a, 2003b). This tool has been used in Paleontology to calculate the suitability for fossil prospection in sites of the Two Medicine

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Formation (Upper Cretaceous, Canada and USA; Oheim, 2007), and in the Elliot Formation (Upper Triassic to Lower Jurassic, South Africa; Wills *et al.*, 2018). However, the use of this tool in Paleontology is still rare, and it has never been applied on the Upper Jurassic of Portugal. The index developed in this work followed the methodology described by Oheim (2007), following the weighted factors used therein. The municipality of Lourinhã was selected as the area of study due to its vast paleontological heritage with numerous fossil occurrences originated from continental Upper Jurassic deposits. This continental sequence cropping out in the Lourinhã region is part of the Upper Jurassic–Lower Cretaceous sequence deposited during the third rifting episode of the Lusitanian Basin (Kullberg *et al.*, 2006), a period marked by the internal differentiation of this basin into several sub-basins. After the Kimmeridgian, the sedimentary sequence was strongly siliciclastic, with a continental signature at the top of the sequence (Hill, 1989). In more than 150 years of paleontological research in the Lourinhã region, several iconic specimens and new species have been found, including some of the oldest and most emblematic examples of tetrapod material in Portugal (e.g. Lapparent & Zbyszewski, 1957). This superclass has been chosen as the focus of the analysis.

2. OBJECTIVES

Through the mapping of a suitability index for tetrapod remains present in the Upper Jurassic deposits in the Lourinhã area, it is possible to constrain the areas with a higher likelihood of producing fossils. This method could contribute for survey and preparation of launching prospection campaigns and possibly making them more time and money efficient. The application of this index can also be a useful tool to cross-reference with occurrence reports provided by the local populations.

3. METHODOLOGY

The methodology used herein is an adaptation of the predictive indexes present in Oheim (2007), consisting of a weighted sum between four factors: Geology, Elevation, Vegetation and Road Network Proximity. The data used was geospatial, so a package of Geographic Information Systems, ArcGIS Pro (version 3.1.441833), was necessary to build the index. While processing the data, was observed that the municipality of Lourinhã is more transformed by urban activity than the vast area of the Two Medicine Formation. For that reason, a land usage replaced the vegetation factor in the index. Associated classes of this factor were subsequently adapted.

Factors	Source	Classes	
Geology	WMS Server of LNEG, geoPortal of LNEG.	Presence of tetrapod fossils	4
		Absence of tetrapod fossils	0

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Factors	Source	Classes	
Elevation (m)	OpenTopography - Copernicus GLO-30 Digital Elevation Model. Classes done according to the Natural Breaks (Jenks) method.	209-136	4
		136-105	3
		105-73	2
		73-41	1
Land Usage	Carta de Ocupação do Solo Simplificada de 2021 | DGT.	Urbanizations	1
		Farmland	2
		Forest	3
		Pasture	4
		Rivers, quarries and cliffs	5
Road Network Proximity (km)	Rede Rodoviária Nacional (RRN) - dados.gov.pt - Portal de dados abertos da Administração Pública. Classes done according to Oheim, 2007	3,2-2,4	1
		2,4-1,6	2
		1,6-0,8	3
		0,8-0	4

Table 1. Source and weight of each factor and class, respectively, of the index.

For the geologic factor was used a correlation between the two geological maps at the scale 1:50000 (30-A: Lourinhã, and 30-B: Bombarral), published by Laboratório Nacional de Energia e Geologia (former Portuguese Geological Survey), that comprise most of the Lourinhã municipality (Tab. 1). The different units represented in these maps were correlated according to Mateus *et al*. (2017; see Tab. 2). Finally, the data was fed to the following suitability index equation:

Suita_index = ((Land Usage x 0.2) + (Geology x 0.4) + (Elevation x 0.3) + (Road Network Proximity x 0.1)) x 4

Age (*sensu* Mateus *et al*., 1999)	**Map 30-A** (Manuppella *et al*., 1999)	**Symbol**	**Map 30-B** (Zbyszewski *et al*., 1966)	**Symbol**	**Vertebrate tetrapod fossils**
Oxfordian	Calcários de Montejunto	J^3_M	Parte superior de: Camadas de Cabaço e de Montejunto	J^3_{ab}	No
lower Kimmeridgian/Kimmeridgian	Grés, margas, calcários oolíticos e dolomitos da Consolação	J^3_{Co}	Parte inferior de: Camadas da Abadia	J^3_C	No
upper Kimmeridgian	Grés, margas e arenitos de Praia da Amoreira e Porto Novo	J^3_{AP}	Parte superior de: Camadas da Abadia + Parte inferior de: Complexo Pteroceriano, incluindo as Camadas com "*Lima pseudo-alternicosta*"	$J^3_C + J^4$	Yes
upper Kimmeridgian/lower Kimmeridgian	Margas, argilas e grés do Sobral	J^3_{SO}	Parte superior de: Complexo pteroceriano incluindo as Camadas com "*Lima pseudo-alternicosta*"	J^4	Yes

Age (*sensu* Mateus *et al.*, 1999)	**Map 30-A** (Manuppella *et al.*, 1999)	**Symbol**	**Map 30-B** (Zbyszewski *et al.*, 1966)	**Symbol**	**Vertebrate tetrapod fossils**
Titonian/Lower Berriasian	Grés, margas, argilas e conglomerados do Bombarral (Grés superiores)	J^{3}_{BO}	Camadas de Freixial	J^{5}	Yes
Berriasian	Siltes arenosos, argilas e grés grosseiro de Serreira + Grés fino a grosseiro argiloso de Vale de Lobos	C^{1}_{Se} + C^{1}_{VL}	Grés com vegetais fósseis, de Torres Verduras e do Cercal	C^{1-2}	No

Table 2. Correlation between the stratigraphic units present in the maps 30-A and 30-B of the Carta Geológica de Portugal at the scale 1:50000.

4. RESULTS AND CONCLUSIONS

After calculating the suitability index (Fig. 1) it was possible to conclude that the geology and the land usage were the most determinant factors for the presence of tetrapod fossils in the region. Areas with higher suitability values are rare and scattered, except in the northeast, and represent an overall area of 39 km^2 (26%). We also observed that higher suitability values are more common with higher altitudes. Medium suitability values represent an overall area of 78,56 km^2 (54%), and due to the wider extent, appear less scattered. Finally, lower suitability values tend to be in highly urbanized areas and represent an overall area of 29,55 km^2 (20%). This methodology only considered the geology in 2D, disregarding the topology so places with vertical presence of fossiliferous strata, such as cliffs, appear to have a low suitability index. The resulting values of the index vary between 3,6 and 12, close to the values in Oheim (2007), which are between 8,8 and 16. The elevation factor was originally used for the Two Medicine Formation as a representation for the stratigraphy of the area, because it is mainly characterized by horizontal strata (Oheim, 2007). In future it would probably be better to add the slope factor or replace elevation by the slope, due to differential slope across an area contributing to different levels of erosion. Geology is the factor with the greatest weight, so it could be causing index issues due to the quality of the data. The geological information for Bombarral was published in 1966 (Zbyszewski *et al.*, 1966), and used an outdated and more generalized stratigraphic classification. The lack of resolution in the geological data directly affects the results. On the other hand, the utilization of land, despite being given less consideration, seemed to have a significant influence as well. It restrained prospection to the less urbanized areas in the municipality, a problem probably not faced in the greatly unadulterated Two Medicine Formation (Oheim, 2007).

Most of our area was already within 0,8 km within a main road, making this factor less impactful and as such less useful for the analysis overall. In the future we plan to corroborate the data obtained through the index with field work. In any case it was possible to constrain the prospecting area

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from 147,2 km² to 39 km², and to establish a map that can be used as reference for future prospecting works in the region.

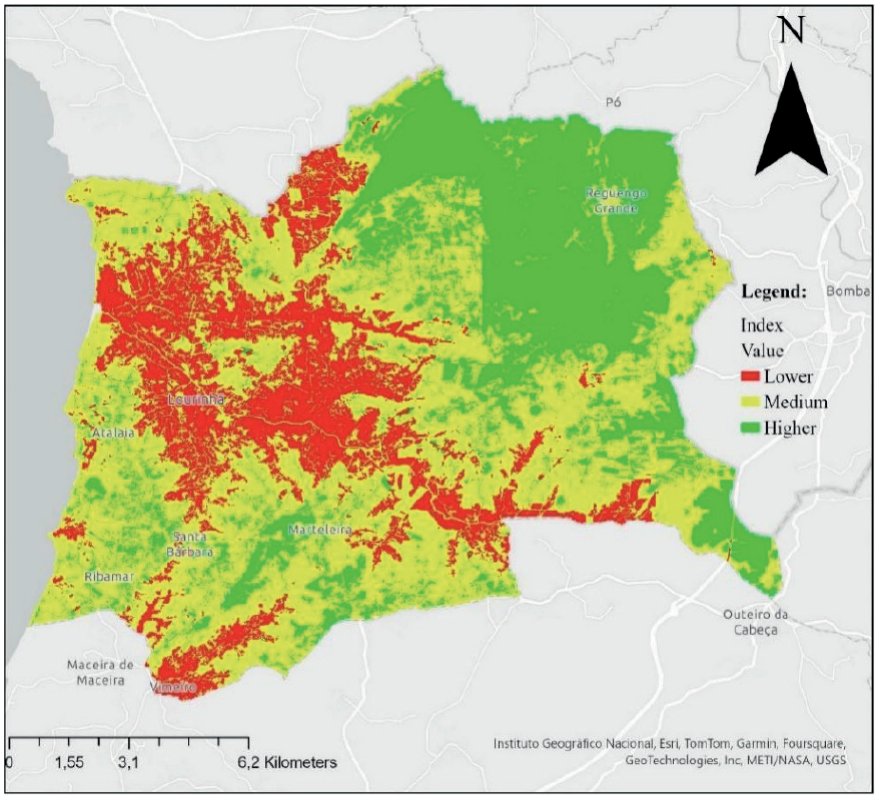

Figure 1. Suitability areas for the prospection of tetrapod fossils superimposed on the Lourinhã municipality map.

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