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# Habitat preferences of diurnal raptors in relation to human access to their breeding territories in the Balkan Mountain Range, Bulgaria

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## Abstract

**Background:** In this study we examined the habitat preferences of three diurnal raptors in relation to human access. We aimed to identify the selection of breeding habitat by the Golden Eagle (*Aquila chrysaetos*), the Long-legged Buzzard (*Buteo rufinus*), and the Peregrine Falcon (*Falco peregrinus*) in response to site accessibility by humans, and in turn, the response of these species to human presence.

**Methods:** Data about the nest locations were collected. Analyses and maps were created using ArcGIS. The “least cost path” was defined using the Cost Path tool.

**Results:** The lowest values of the Cost Path were established for Long-legged Buzzard and the highest values were estimated for Golden Eagle. Intermediate Cost Path values for Peregrine Falcon were found.

**Conclusions:** The Long-legged Buzzard could be considered as the most tolerant to human presence in its breeding territories. The Golden Eagle have the lowest degree of tolerance and the Peregrine Falcon is ranked in an intermediate position compared to the other two species, but closer to Golden Eagle.

**Keywords:** Anthropogenic impact, Golden Eagle, Least cost path, Long-legged Buzzard, Peregrine Falcon

## Background

Raptors are generally used as indicators of anthropogenic effects, as they are higher order predators, long lived, require large territories, and are often sensitive to habitat change (Newton 1979; Russo 2006; Sergio et al. 2006; Carrete et al. 2009). Identifying the factors governing the nesting habitat selection of raptors with high conservation status may be of primary importance in determining the conservation objectives. Environmental variables are often at the forefront of habitat selection studies for raptors however we also need to consider the effect

of anthropogenic factors in influencing habitat selection. Human activities impact the raptors by altering the characteristics of their habitats (Watson 1991, 1992; Xirouchakis 2001; Russo 2006; Whitfield et al. 2007; Demerdzhiev et al. 2014). In many instances human presence in the breeding territories causes disturbance of the pairs, which are particularly sensitive in pre-reproductive and reproductive periods (Tjernberg 1983; Andersen et al. 1990; Watson and Dennis 1992; Alivizatos et al. 1998; Pedrini and Sergio 2001; Redinov 2010; Spaul and Heath 2016, 2017; Perona et al. 2019).

Accessibility for people is an important predictor of direct and indirect human impact on ecosystems (Trombulak and Frisell 2000). Accessibility is determined by the available paths and transport infrastructure, by the

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terrain slope and unevenness, the natural water barriers, and the vegetation permeability. Tourism and recreational activities (e.g. rock climbing, caving, hang gliding and paragliding, and winter sports) are also an important aspect, in terms of how people use the different accessibility areas. Despite the obvious importance of accessibility, its quantification is intricate. Simple measuring of the distance is often used as the easiest quantification of accessibility, which neglects the influence of topography, water features and vegetation. The ArcGIS tools Cost Distance and Cost Path enable a more sophisticated approach to quantifying accessibility by taking into account the slope of the landscape to be traversed. In the context of ecology, “the least cost path” analysis is traditionally employed mainly to assess the functional connectivity of landscapes for species and determine sites that are potentially used as dispersal routes or that should be conserved as biological corridors (Schadt et al. 2002; LaRue and Nielsen 2008; Jobe and White 2009). Accessibility models can be used to analyze the impact of tourism as well as other human impacts on protected areas in order to identify more appropriate management and protection measures (Esteves et al. 2011). They also reduce costs and increase efficiency in conducting environmental studies (Greenwood 1996).

The Golden Eagle (*Aquila chrysaetos*) (Linnaeus 1758) and the Peregrine Falcon (*Falco peregrinus*) (Tunstall 1771) were abundant in Bulgaria until the beginning of the twentieth century, with their populations declining thereafter (Simeonov et al. 1990). The Golden Eagle population in Bulgaria is estimated at 120–150 pairs (Petrov et al. 2015), and the Peregrine Falcon population has been estimated at 200 pairs (Ragyov et al. 2008; Stoyanov et al. 2015). The Long-legged Buzzard (*Buteo rufinus*) (Cretzschmar 1827) is recorded as a breeding species in Bulgaria, and its breeding population was recently estimated at 800–1000 pairs (Vatev et al. 2015). These species of raptors are common in the Balkan Mountain Range but are of high conservation importance on a national level. All three species are protected by the Bulgarian Biological Diversity Act. The Golden Eagle and Long-legged Buzzard are also listed in the Red Data Book of the Republic of Bulgaria under the category VU–Vulnerable (Petrov et al. 2015; Vatev et al. 2015), while Peregrine Falcon is listed as EN – Endangered (Stoyanov et al. 2015).

Golden Eagle is known to live in various rocky habitats in proximity to open areas is of importance. In Bulgaria, its nests are positioned predominantly on cliffs, but also have been found on trees (Simeonov et al. 1990; Milchev and Georgiewa 1992; Milchev 1994; Petrov et al. 2007).

Long-legged Buzzard resides on cliffs, in stone quarries near deforested mountain slopes or other open spaces,

on hilly foothills (Simeonov et al. 1990; Vatev et al. 2015). It is also found near wetlands of various types (Michev et al. 1984; Vatev 1987). Its nests are placed on cliffs, trees and quarries (Boev 1962; Michev et al. 1984; Vatev 1987; Simeonov et al. 1990; Milchev 2009; Demerdzhiev et al. 2014). Peregrine Falcon inhabits rocky terrains, near open spaces, sometimes with scattered trees and patchy woodland. Very rarely, it occurs in settlements (Simeonov et al. 1990; Stoyanov et al. 2007, 2015). This species prefers for nesting steep, high cliffs with a dominant position to the landscape, which are found in many areas of its range (Gainzarain et al. 2000; Jenkins 2000; Sergio et al. 2004; Jenkins and van Zyl 2005; Brambilla et al. 2006; Ragyov et al. 2008; Karyakin and Nikolenko 2009).

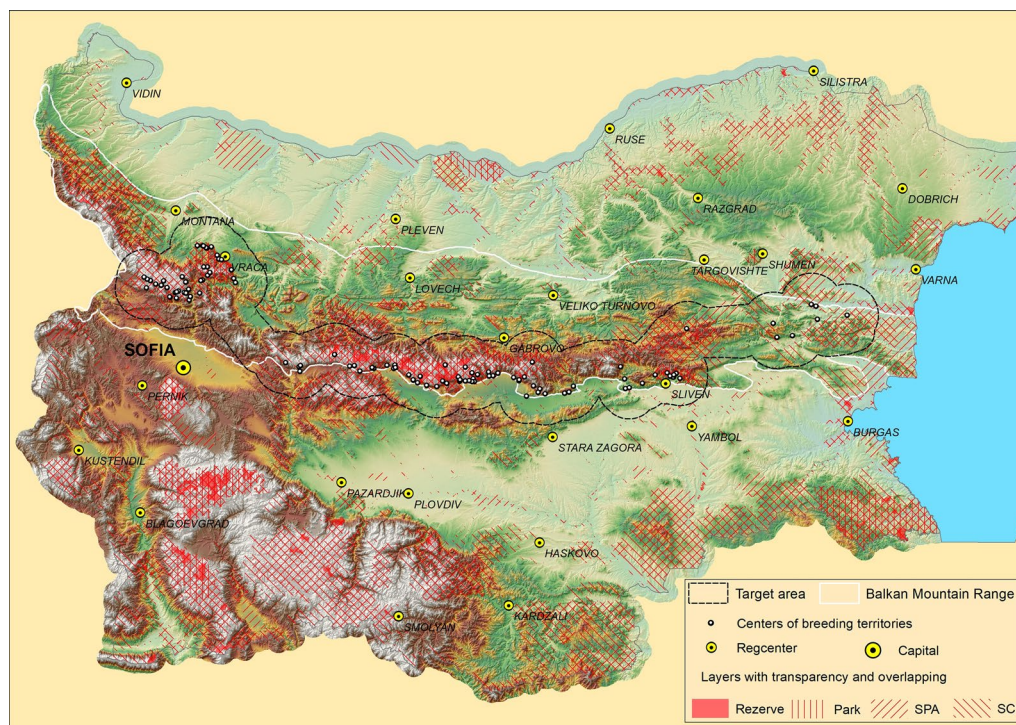
The European Ecological Network Natura 2000 is a fundamental tool for the conservation of many bird species and their habitats in the European Union, the main purpose of which being to cover the most suitable areas for the survival and reproduction of the target species of birds in protected areas (Fernández and Gurrutxaga 2010). The protected areas (parks and reserves) form the core of the biodiversity conservation in Bulgaria. Studies on the selection of breeding territories by protected raptors in relation to human access to their territories can be helpful in creating effective conservation plans and in the design of protected areas.

We formulated a working hypothesis that accessibility is an important factor in the choice of breeding habitat for Golden Eagle, Long-legged Buzzard and Peregrine Falcon, which can be quantified and used as a reliable indicator in assessing anthropogenic impact. We aim to identify the selection of breeding habitat by the Golden Eagle, the Long-legged Buzzard, and the Peregrine Falcon in response to site accessibility by humans, and to compare the response of these species to human presence.

## Methods

### Study area

Balkan Mountain Range is the largest mountain range in Bulgaria covering an area of 11,596 km<sup>2</sup>. Balkan Mountain Range has a length of 530 km and its width ranges between 15 and 45 km. The average altitude is 722 m, with Botev Peak being the highest point at 2376 m (Fig. 1). A mountainous variety of the temperate continental climate is predominating in the Balkan Mountain Range. The seasonal precipitation distribution corresponds to the moderate continental retention regime. The forests are mainly deciduous, dominated by European Beech (*Fagus sylvatica*), Hornbeam (*Carpinus betulus*), Durmast Oak (*Quercus petraea*), and with local occurrences of Moesian Beech (*Fagus sylvatica moesiaca*), Sweet Chestnut (*Castanea sativa*), Turkey Oak (*Q. cerris*), and Hungarian Oak (*Q. frainetto*). The coniferous



**Fig. 1** Map of the study area with the breeding territories of the three species under study recorded

forests do not form a continuous coverage in the mountain. They are represented mostly by Norway Spruce (*Picea abies*), but Scots Pine (*Pinus sylvestris*) and Macedonian Pine (*Pinus peuce*) are also found. Alpine grass vegetation is present in the highest zone (Kopralev 2002). The Balkan Mountain Range is a biodiversity rich region for fauna. Forest habitats maintain the majority of the faunal biodiversity, but alpine regions also contribute to the biodiversity of the area (Gruev and Kuzmanov 1994). Part of the territory of the study area is included in the European Ecological Network Natura 2000 and Protected Areas, which are presented in Fig. 1.

#### Field work

Data collection on the location of Golden Eagle, Long-legged Buzzard and Peregrine Falcon nests within the territory of the Balkan Mountain range took place between March and July during the period 2006–2010. Prior to the study, potential nesting sites such as cliff formations and solitary cliffs were identified based on reports of previous cases of nesting. Also, a survey of topographic maps and maps of Google Earth™ was performed. Potential locations were explored from an optimal distance, depending on the field conditions. The terrain was scanned using binoculars with a laser rangefinder and a spotting scope. The centers of the breeding territories were determined

either based on nests found or indirectly based on birds' behavior. GPS device, binoculars' laser rangefinder, and a compass were also used. In some cases, the exact location of the nest was not possible to be fixed due to topographic features and/or risk of unnecessary disturbance to the birds. However, most of these cases were related to single-standing small cliffs and the exact position of the nest was estimated within an acceptable error of up to 10–20 m. A total of 38 territories (29 localized nests) of Golden Eagle, 54 territories (38 nests) of Long-legged Buzzard and 20 territories (6 nests) of Peregrine Falcon were identified (Fig. 1).

#### GIS analyses

The analyses and maps were created using ArcGIS 10.6 (ESRI, Redlands, CA, USA).

#### Input layers

Input layers are presented in Table 1.

#### Cost Distance and Cost Path tools

In this study, we regarded accessibility as an integral characteristic which is inversely proportional to the effort that people have to make to reach a certain point. Accessibility of certain point (e.g. center of the breeding territory) is determined from a given starting point

**Table 1** Input layers

Name of layer	Modifications	Original source
Centers of breeding territories	Point layer created by GPS coordinates	Authors' field data
Settlements	Point layer created by GPS coordinates	JICA_Core_DB.mdb
Roads	Line layer created after detailing by use of topographic map JICA_DB_TopoMap_2500	JICA_Core_DB.mdb/T_BgRoad
Starting point on the Roads	Point layer created by points obtained after calculating of the shortest distance between Centers of breeding territories and Roads	Roads (modified) and Centers of breeding territories
Lodges	Point layer created by GPS coordinates from several specialized portals	<a href="http://www.bulgarian-mountains.com">www.bulgarian-mountains.com</a> ; <a href="http://www.btsbg.org">www.btsbg.org</a> ; <a href="http://www.tourism-bg.net">http://www.tourism-bg.net</a> ; <a href="https://www.planinote.info/">https://www.planinote.info/</a> ; <a href="https://opoznai.bg/">https://opoznai.bg/</a> ; <a href="http://www.hijji.tourism-bg.net/">http://www.hijji.tourism-bg.net/</a>
Routes	Tourist routes and trails	<a href="http://www.bgmountains.org">www.bgmountains.org</a> and JICA_Core_DB.mdb/T_BgRoad
Starting point on the Routes	Point layer created by points obtained after calculating of the shortest distance between Centers of breeding territories and Routes	Routes and Centers of breeding territories
Religious tourism centers (monasteries and chapels)	Point layer created by points taken from a topographic map	JICA_DB_TopoMap_25000
Quarries/mines	Point layer created by GPS coordinates	<a href="http://www.mi.government.bg/bg">www.mi.government.bg/bg</a>
Starting points for rock climbing	Point layer created by GPS coordinates	<a href="http://www.climbingguidebg.com">www.climbingguidebg.com</a>
Starting points for hang gliding and paragliding	Point layer created by GPS coordinates	<a href="http://www.skynomad.com">www.skynomad.com</a>
Caves	Point layer created by points taken from a topographic map	JICA_DB_TopoMap_25000
Waterfalls	Point layer created by GPS coordinates	Nikolov (2013)
Lift stations	Point layer created by points taken from a topographic map	JICA_DB_TopoMap_25000
Special Protection Areas (SPA)	–	N2000_BG_120_ptici_2019.shp <a href="http://natura2000.moew.government.bg/Home/Documents">http://natura2000.moew.government.bg/Home/Documents</a>
Sites of Community Importance (SCI)	–	N2000_BG_234_mestoobitania_2019.shp <a href="http://natura2000.moew.government.bg/Home/Documents">http://natura2000.moew.government.bg/Home/Documents</a>
Protected Areas under the Protected Areas Act	–	zpo_all.shp <a href="http://eea.government.bg/zpo/bg/index_download.jsp">http://eea.government.bg/zpo/bg/index_download.jsp</a>
Digital Elevation Model (DEM)	Raster with 30 m pixel size, transformed to UTM35N and resampled to 20 m pixel size	Shuttle Radar Topography Mission (SRTM) <a href="https://earthdata.nasa.gov/nasa-shuttle-radar-topography-mission-srtm-version-3-0-global-1-arc-second-data-released-over-asia-and-australia">https://earthdata.nasa.gov/nasa-shuttle-radar-topography-mission-srtm-version-3-0-global-1-arc-second-data-released-over-asia-and-australia</a>

(e.g. settlement) and is inversely proportional to the sum of the slope along the flattest path between the two. The ArcGIS Cost Path tool was used to calculate “the least cost path” but the application of Cost Distance was needed as a preliminary step. In this case, when using the Cost Distance tool, for each pixel on the map, its slope was counted. The slope is the most important parameter for calculating “the total energy cost” to move from the starting point to the certain point, compared to altitude, exposure, and other parameters in mountain areas in the temperate latitudes and at altitudes up to 2000 m (Minetti et al. 2002; Jobe and White 2009). First based on an elevation raster a new slope raster is created using

ArcGIS Slope tool. For each pixel, the tool calculates the rate of change in elevation from that pixel to its neighbors in east–west direction (*x*-axis) and north–south direction (*y*-axis) and uses trigonometry to determine the overall slope in degrees. Finally, the least-cost path from a source to a destination is created. The algorithm works by iteratively expanding the source and destination’s neighboring pixels like circular waves and recomputing the least-cost required to reach them given the new wave front.

To calculate the cost distance, depending on the specific task, its formula needs to be adapted to produce a result that can be related to the ecology of the species and the analyzed environmental parameters and factors. In the



present case, the following initial formula for cost distance was used:

$$\text{Cost distance} = \min_{pa} \sum_{ant}^{rp} \text{Slope (input\_pixel)} \\ \times \text{Multiplier (active\_population)}$$

where the symbols “pa” means path, “rp” result pixel, and “ant” antropogenic point.

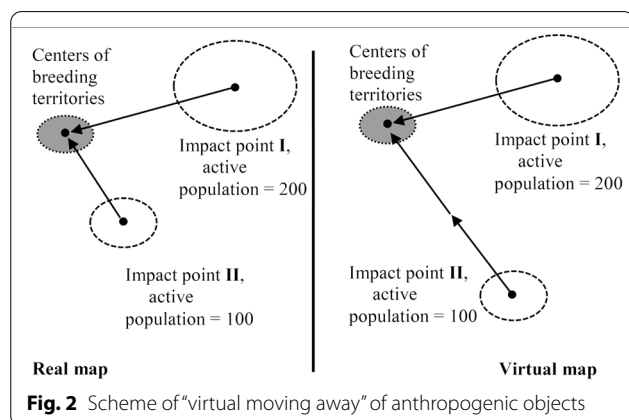
Multiplier is a function of active\_population and determines the relationship between cost distance and active population. The relationship between the Multiplier and the active population is inversely proportional. In the simplest case, the relation is described by the  $1/x$  function:

$$\text{Multiplier (x)} = 1/x$$

Graphically, it can be depicted as a virtual moving away of anthropogenic objects at a distance inversely proportional to their active population (Fig. 2).

The active population in the present sample was within a range of 1 to 77,411. In the case of the bigger settlements (population over 10,000), the  $1/x$  function assigned so much importance to the large number of inhabitants that those settlements completely dominated the rest of the settlements in determining the disturbance of the breeding pairs as a result of human presence (using cost distance and cost path). In order to correct that bias and to achieve a more objective impact assessment for multiplier for bigger settlements with population more than 10,000, it was assumed that with the population exceeding 10,000 residents, disturbance increased negligibly. Hence, a threshold of 10,000 was introduced:

$$\text{Multiplier} = \frac{1}{\min(\text{active\_population}, 10,000)} \quad (1)$$



In the sorted sample (without repeats), the ratio  $r$  between two consecutive values varied between 1 and 2.5. In this model, the influence of the sources with the lowest numbers was negligible and it could be disregarded in practice. To achieve a more objective impact assessment, the ratio  $r$  needed to be minimised. The effect of the source of impact was omnidirectional and could be considered as a circle (two-dimensional object). The multiplier was a one-dimensional scalar revealing the virtual “distance” from the nest. The most direct relationship between those two was a square root. Thus, the ratio  $r$  would vary between 1 and  $\sqrt{2.5} \approx 1.58$ , and formula (1) was changed accordingly:

$$\text{Multiplier} = \frac{1}{\sqrt{\min(\text{active\_population}, 10,000)}} \quad (2)$$

Formula (2) yielded values in the range of 0.01 to 1. To obtain values in the range of 1 to 100, the following formula was used:

$$\text{Multiplier} = \frac{100}{\sqrt{\min(\text{active\_population}, 10,000)}} \quad (3)$$

When applying formula (3), this reflected in the cost path geometry as an increased likelihood of connecting nearer and smaller settlements to the center of the breeding territory than the cost path obtained without the use of a square root.

In order to make a general analysis to determine the joint disturbance that all anthropogenic objects may cause, their multiplier values must be comparable. In our case, the active population indicator, for which there were accurate data on the settlement’s population numbers, was taken as a base. In the cases of incomplete data for other anthropogenic objects and data of indirect origin, values based on expert knowledge were given.

## Analyses

The Cost Path analyses are presented in Table 2. Sample section of the study area presenting the results obtained using Cost Path tool is shown in Fig. 3.

## Statistical analyses

STATISTICA V. 12 (StatSoft Inc. 2014) was used for the statistical analysis of the data. We used Spearman’s rank correlation coefficient to determine the presence or absence of correlation. We used descriptive statistics to calculate mean, minimum, maximum and standard deviation of the cost path values of various impact points (anthropogenic objects) for all three species of the raptors under study. Non-parametric

**Table 2** Cost Path analyses**Cost Path analyses**

Cost Path from settlements to the centers of breeding territories<sup>a</sup>

Cost Path from roads to the centers of breeding territories

Cost Path from operating lodges to the centers of breeding territories<sup>b</sup>

Cost Path from pedestrian routes to the centers of breeding territories

Cost Path from religious tourism centers to the centers of breeding territories

Cost Path from operating quarries or mines to the centers of breeding territories

Cost Path from starting points for recreational activities (rocks used for rock climbing, starting points for hang gliding and paragliding, caves, waterfalls, and lifts) to the centers of breeding territories

Cost Path All—Cost Path from any point of an anthropogenic object in the united layer to the centers of the breeding territories

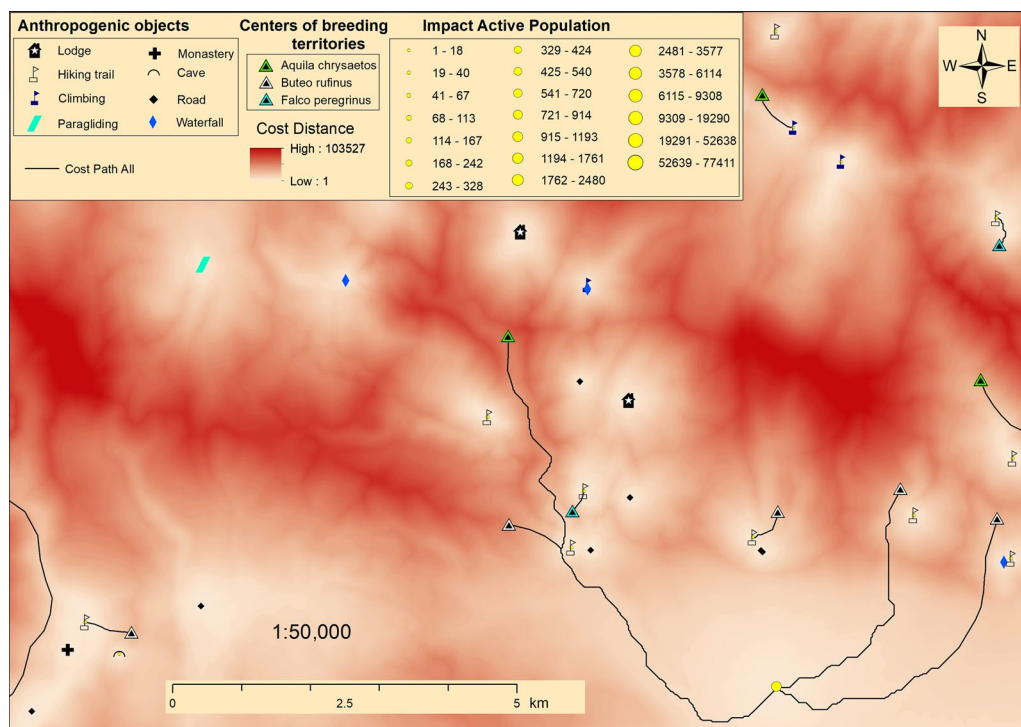
Percentage distribution of breeding territories in relation to Natura 2000 areas—special Protection Areas (SPA) and Sites of Community Importance (SCI)

Percentage distribution of breeding territories in relation to Protected Areas—parks and reserves<sup>c</sup>

<sup>a</sup> The population numbers of the settlements were set as an additional condition in the calculation of the cost path. For this purpose, data from the 2011 census of the National Statistical Institute ([www.nsi.bg](http://www.nsi.bg)) were used, taking into account the number of the active population, which included people aged 5 to 70 years

<sup>b</sup> The capacity in terms of number of beds in the Balkan Mountains lodges was set as an additional condition in the calculation of the cost path

<sup>c</sup> In cases where the breeding territory fell simultaneously in the two types of Protected Areas, the Protected Area with a higher status was predominantly taken into account



**Fig. 3** Map of a sample section of the study area presenting the results obtained using Cost Path. The centers of the breeding territories are virtual points obtained after a deliberate change of the real location in order to prevent illegal actions on the protected species

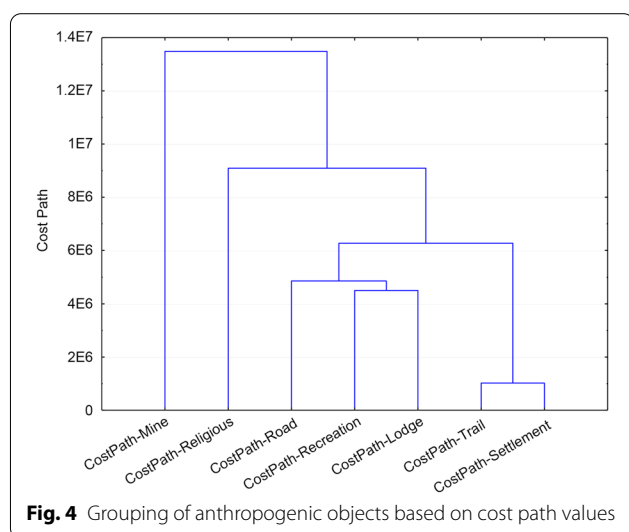
one-way ANOVA was used in comparing requirements for the location of breeding territories of the three species in terms of accessibility. Cluster analysis was used to classify anthropogenic objects into relative groups.

## Results

For all three species, the maximum mean cost path belonged to quarries and mines, suggesting that they would also have the lowest potential impact on the

**Table 3** Descriptive statistics of the cost path values of various impact points (anthropogenic objects) calculated for all three species under study

Cost path	<i>Aquila chrysaetos</i> (n = 38)				<i>Buteo rufinus</i> (n = 54)				<i>Falco peregrinus</i> (n = 20)			
Impact points	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
Settlement	90,609	22,440	280,375	55,517	59,465	5587	170,656	39,839	75,266	22,156	223,431	47,958
Lodges	572,636	139,370	1,005,450	233,616	716,139	188,531	1,316,020	239,448	563,885	126,458	1,185,330	309,488
Road	772,518	154,350	2,120,293	536,853	405,925	16,532	1,535,778	296,832	611,835	83,041	1,995,407	510,412
Trail	133,723	13,197	306,222	80,500	80,627	4863	265,758	65,269	138,805	31,999	374,660	83,476
Quarries/Mines	2,352,757	533,792	5,816,220	1,413,244	1,585,221	183,749	3,637,854	840,781	2,203,449	213,645	4,897,610	1,195,145
Religious	1,357,485	177,925	2,818,153	619,713	920,064	90,372	2,138,050	481,457	1,456,415	458,864	3,881,310	768,204
Recreation	688,855	116,479	1,615,979	371,224	534,988	18,901	1,397,080	320,524	556,976	67,935	1,487,392	361,736
All	71,433	13,197	149,412	37,897	42,604	4863	130,039	30,751	64,827	22,390	128,624	33,508



breeding behavior of these breeding species. The greatest possible impact would be expected from settlements and tourist trails. The smallest cost path values were found

for Long-legged Buzzard, indicating that the potential impact of the anthropogenic objects is strongest for this species. The maximum values of cost path were detected for the Golden Eagle, respectively, the potential impact of the anthropogenic objects is the least for this species (Table 3).

The results of the correlation analysis showed lack of correlation between the variables (Spearman  $r < 0.7$ ;  $n = 112$ ;  $p < 0.05$ ).

Based on the cost path values, a grouping of the anthropogenic points is presented in Fig. 4.

The results of non-parametric one-way ANOVA are presented in Table 4. Comparing the three species, the most pronounced differences were found between the Long-legged Buzzard and the Golden Eagle. The selection of breeding territories in terms of accessibility in these two species differs significantly and reflects their different response in terms of human presence near the nest. The lack of statistically significant differences between the Peregrine Falcon and the Golden Eagle suggests that the two species exhibit very similar requirements for the

**Table 4** Comparison of cost path values between Golden Eagle (GE), Long-legged Buzzard (LLB) and Peregrine Falcon (PF) using non-parametric one-way ANOVA

Cost path Impact points	Kruskal–Wallis test: $H$ (2, $n = 112$ )	$p$	GE vs. LLB		GE vs. PF		LLB vs. PF	
			$z$	$p$	$z$	$p$	$z$	$p$
Settlement	9.418431	0.0090	3.0616 <sup>a</sup>	0.0066 <sup>a</sup>	1.1874	0.7052	1.2234	0.6635
Lodge	8.924810	0.0115	2.5767 <sup>a</sup>	0.0299 <sup>a</sup>	0.1910	1.0000	2.2858	0.0668
Road	14.09659	0.0009	3.7219 <sup>a</sup>	0.0006 <sup>a</sup>	1.2334	0.6522	1.7090	0.2624
Trail	15.21118	0.0005	3.3937 <sup>a</sup>	0.0021 <sup>a</sup>	0.1898	1.0000	2.9455 <sup>a</sup>	0.0097 <sup>a</sup>
Quarry/mine	7.910001	0.0192	2.5139 <sup>a</sup>	0.0358 <sup>a</sup>	0.0047	1.0000	2.0286	0.1275
Religious	16.75166	0.0002	3.5105 <sup>a</sup>	0.0013 <sup>a</sup>	0.3001	1.0000	3.1563 <sup>a</sup>	0.0048 <sup>a</sup>
Recreation	5.810528	0.0546	2.3489	0.0565	1.5452	0.3669	0.2693	1.0000
All	18.41045	0.0001	4.0845 <sup>a</sup>	0.0001 <sup>a</sup>	0.6638	1.0000	2.6034 <sup>a</sup>	0.0277 <sup>a</sup>

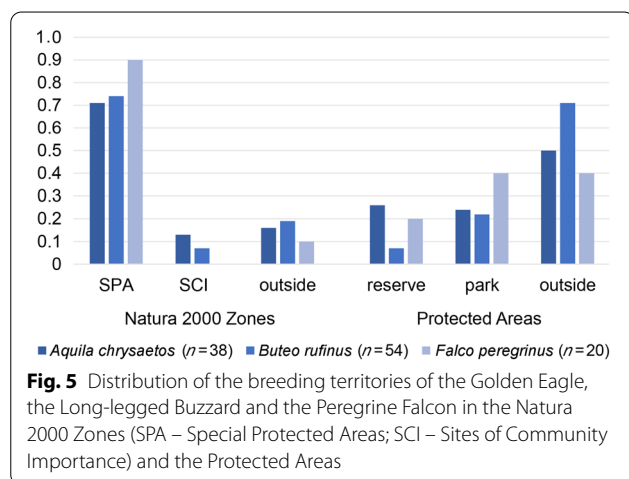
<sup>a</sup> Denotes statistically significant differences between species

location of breeding territories in terms of accessibility (Table 4).

The analyses on the distribution of the Golden Eagle, Long-legged Buzzard and Peregrine Falcon breeding territories in the Natura 2000 zones and the Protected Areas in the Balkan Mountains (Fig. 5) showed that Natura 2000 zones covered 84% of the Golden Eagle territories, 81% of the Long-legged Buzzard and 90% of the Peregrine Falcon territories. The Protected Areas were found to include 50%, 29% and 60% respectively of the territories of the three studied species of raptors.

## Discussion

Using the average cost path, we segregated anthropogenic effects into the three groups. Group one encompassed quarries, mines and religious centres. Group two included lodges, roads and recreational activity starting points while group three included settlements and pedestrian routes. The anthropogenic objects of the group one had the highest cost path values for all three bird species. Those were “the highest cost anthropogenic objects”, meaning that the centers of the breeding territories were the most difficult to access from those points. Hence, quarries, mines, and religious tourism centers had the least impact and the lowest degree of significance as a source of anthropogenic invasion to the breeding territories. The anthropogenic objects of the group two were characterized by similar but lower cost path values. The anthropogenic objects of the group three had the lowest cost path values, i.e. those were “the least cost anthropogenic objects”. The centers of the breeding territories were the most easily accessible from those points, hence they were considered to be the most significant and the most affecting the three bird species in the surveyed area. This was also supported by Cost Path All analysis of the united layer including all anthropogenic objects.



Golden Eagle is characterized as sensitive to human disturbance (Andersen et al. 1990; Watson 1997). The species positions its breeding territories to avoid the proximity of anthropogenic effects. Shafaeipour (2015) suggests that the Golden Eagle selects cliffs that are remote from roads and settlements for nesting. Evidence indicates that easily accessible nesting sites are more vulnerable with higher breeding failure in comparison to those that are more difficult to access (Watson and Dennis 1992). Tourism expansion has steadily increased indirect disturbance within breeding territories (Perona et al. 2019). Recreational activities such as rock climbing, paragliding, mountain biking and snowboarding may increase breeding failure and reduce the foraging habitat available for Golden Eagles (Spaul and Heath 2016). Reduced foraging area increases the energy budget required by adult eagles and predisposes nestlings to increased predation (Tjernberg 1983; Pedrini and Sergio 2001). Proportionally, occupied territories decrease near tourist destinations (Kaisanlahti-Jokimäki et al. 2008). The territories occupied by Golden Eagle are characterized for the most part by low levels of disturbance (Xirouchakis 2001; Tapia et al. 2008) and a low density of the human population (Vazhov 2012). In the present study, the highest mean values of the cost path for Golden Eagle, as well as the highest mean values of the Cost Path All, characterized it as the species with the lowest degree of tolerance to human presence, occupying the most difficult to access territories. The major parts of the breeding territories of Golden Eagle (84%) in the Balkan Mountains were found to be within Natura 2000 zones and only half of the territories were covered by protected areas. That is very insufficient, given the high conservation status of the species in Bulgaria, the sensitivity of Golden Eagle to anthropogenic factors and the fact that 46.7% of its national population resides in the Balkan Mountains (Vatev et al. 2015; Petrov et al. 2015).

The lowest average values of the cost path in the Balkan Mountains were established for Long-legged Buzzard for all anthropogenic objects, except for the lodges. The highest cost path values for the lodges for Long-legged Buzzard probably due to the specifics of the location of the lodges and it is an accidental departure from the general trend observed in this species. We believe that the occupation of breeding territories by the Long-legged Buzzard is not a function of disturbance from lodges. The results of the Cost Path analysis suggested that Long-legged Buzzard used to set its breeding territories in the most easily accessible by human's zones of the studied area compared to the other two species, so Long-legged Buzzard could be considered as the most tolerant to human presence. The major parts of the breeding territories of Long-legged Buzzard (81%) were found to be



within Natura 2000 zones and only 29% of the territories were covered by protected areas. That is very insufficient, given the high conservation status of the species in Bulgaria and that the bulk of the European Long-legged Buzzard population lives on the Balkan Peninsula (Mrlik and Landsfeld 2002; Stoychev and Demerdzhiev 2020).

Although Peregrine Falcon had been reported to breed in settlements and quarries (Moore et al. 1992, 1997; Crick and Ratcliffe 1995; Cade et al. 1996; Emison et al. 1997; Stoyanov 2003; Brambilla et al. 2006), the calculated average cost path values in this study were relatively high for the species. The average cost path values ranked Peregrine Falcon by its tolerance to human presence in an intermediate position compared to the other two species, but closer to those reported for Golden Eagle. This could be a result of the persecution of the species in Bulgaria for decades until the second half of twentieth century (Ragyov et al. 2008). Most of the breeding territories of Peregrine Falcon (90%) were found to be within Natura 2000 zones and 60% of the breeding territories are in protected areas, placing this species in a better situation than the other two. Perhaps the fact that more breeding territories of the species are in protected areas has a positive effect on the population recovery observed in recent years (Stoyanov et al. 2007; Ragyov et al. 2008).

## Conclusions

The Long-legged Buzzard establishes its breeding territories in the most easily accessible zones, so this species could be considered as the most tolerant to disturbance. Long-legged Buzzard proved to be the most adaptive to anthropogenic presence in its breeding habitats, which could be considered as an advantage to support the range expansion of the species over the last decades. The Golden Eagle is the species with the lowest degree of tolerance, occupying the most difficult territories in terms of human access. Golden Eagle avoided proximity to humans to the highest degree, which identified it as the most sensitive to anthropogenic invasion in its breeding habitat. The Peregrine Falcon is ranked in an intermediate position compared to the other two species. The lack of statistically significant differences between Peregrine Falcon and Golden Eagle suggested that, regarding its response towards human presence in its territory, Peregrine Falcon was closer to Golden Eagle. Natura 2000 coverage is favorable for all three species—most of their breeding territories fall into Natura 2000 zones. The location of the breeding territories of the three species of interest in protected parks and reserves proved to be insufficient, the situation with Golden Eagle and Long-legged Buzzard being particularly adverse. It is recommended that all the permanently occupied territories of

Golden Eagle, Long-legged Buzzard, and Peregrine Falcon be included in the system of the protected areas.

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## Authors' contributions

DR, VB and ND conceived and designed the study. DR and ND performed the field work. ND, JB and VB processed and analyzed the data. ND wrote the manuscript. VB and BPN made comments to the manuscript. VB, BPN and ND read and approved the manuscript. All authors read and approved the final manuscript.

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## Availability of data and materials

The coordinates of the centers of breeding territories will not be made available for public access in order to prevent unscrupulous action on the protected species.

## Declarations

### Ethics approval and consent to participate

This work complies with the current laws of Bulgaria. It was based on simple field observation without any experimental manipulation or damage to the studied birds.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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