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Selection of trees for rubbing by the wild boar (*Sus scrofa*) in the Sidi Boughaba forested Moroccan Ramsar site: Assessment, implications and prospects

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Abstract: Knowledge of mechanisms by which large mammals select rubbing trees (RT) is a major challenge for the effective management of forests and wildlife resources. In this study, we investigated this issue regarding the wild boar (*Sus scrofa*) in the Moroccan forested site of Sidi Boughaba as a case study. We used data from four sets of variables, namely topography, forest type, landscape composition, and microhabitat, measured at 58 rub and control trees, to determine the factors associated with the occurrence of RT by means of generalized linear mixed models. Our results showed that the RT occurrence increased with a high density of red juniper trees and declined with a distance to the nearest footpath. The variation partitioning analysis revealed that the pure fraction of microhabitat was the most robust in explaining this occurrence (adj. $R^2 = 0.17$, $P < 0.001$), followed by that of forest type (adj. $R^2 = 0.05$, $P < 0.05$). A scientific monitoring system must be set up to strike a balance between the availability of forest trees on the one hand and the pressure exerted by wild boars in this internationally important site on the other. It is imperative to test the geographical generality of our results in other Mediterranean forests.

Keywords: game species; rub trees; rubbing behaviour; tree selectivity; Morocco

Knowing a very significant geo-demographic expansion, the wild boar (*Sus scrofa*) remains one of the most widespread species of large mammals in the world (Lee, Lee 2014; Massei et al. 2015; Morelle et al. 2015). This important distribution is mainly attributed to its strong adaptation capacity to different natural and artificial environments, such as mountain ecotypes (Baubet 1998; Rosell et al. 1998), wetlands (Dardaillon 1984; Cosandier 1998; Gimenéz-Anaya et al. 2008), agricultural areas (Morelle et al. 2015), forests (Matas et al. 2021; Khalidah et al. 2021), and even urban areas (Toger et al. 2018; Lewis et al. 2020). It is also a result of favourable changes in climatic conditions (Geisser, Reyer 2005),

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landscape diversity (Acevedo et al. 2006), artificial feeding and management practices (Acevedo et al. 2006), and lack of predators (Acevedo et al. 2006).

In Morocco, the wild boar, the sole large game mammal species (Ichen and Sehhar 2019), is mainly concentrated in three regions, namely the Souss-Massa, in the mountain oases, large plain farms and along rivers, the forest areas in the Centre, and the Oriental, especially in the oueds of Moulouya and Za (Ichen, Sehhar 2019). Overall, wild boar is common in densely vegetated areas, which are far away from human presence and close to water resources (Rho 2015). This game species can cause negative impacts [e.g. trampling, feeding, and predation upon invertebrates, small vertebrates, and eggs of ground-nesting birds (Cappa et al. 2021)] on natural habitats (Giménez-Anaya et al. 2008) and croplands (Lombardini et al. 2017; Rutten et al. 2019; Sarwar 2019; Cappa et al. 2021; Tarvydas, Olgirda Belova 2022). The latter are primarily affected by the safety factors including human presence and distance to the edge of the nearest forests, roads, and rivers (Cocca et al. 2007; Honda, Sugita 2007; Thurfjell et al. 2009)

The marking tree behaviour by this ungulate is known to be a way of chemical signalling and olfactory communications (Jojola et al. 2012; Sergiel et al. 2017; Tomiyasu et al. 2017). It is also considered a form of intraspecific communication and of removing mud and ectoparasites (Clapham et al. 2013; Filipczyková et al. 2017). Although common in the Mediterranean basin, the knowledge of factors affecting the selection of trees for rubbing by the wild boar does not practically exist [see Lee and Lee (2014)]. To date, no study has been aimed to disentangle the factors governing rub tree (RT) selection in forest environments.

Here, we investigated the effects of a series of variables, measured at rubbed trees and an equivalent number of random non-rubbed trees, on the probability of RT occurrence. A marked sensitivity toward an individual predictor will determine the nature and the scope of management measures to be undertaken (Hanane et al. 2022).

The results of this investigation will help inform on the management of this suid species in forests. Given the known ecology of the wild boar, we hypothesized that the selection of RT will depend on (*i*) microhabitat (Luskin et al. 2021; Khalidah et al. 2021; Karami, Tavakoli 2022), and (*ii*) landscape structure (Acevedo et al. 2006).

MATERIAL AND METHODS

Study area. The study was conducted in the Ramsar site of Sidi Boughaba (hereafter SBG) (northwestern Morocco, 34°14'28"N, 6°40'22"W), which has a total surface area of 650 ha (Ramsar 2003), 82.1% of which (i.e. 540 ha) is occupied by forests (Ramsar 2003), 16.9% by the SBG wetland area (110 ha), and 1% (7 ha) by the roads and paths. The lake SBG, located on an elevation range between 0 m to 77 m a.s.l. (Ramsar 2003), lies at a ~6 km length separating the mobile coastal dunes (20–30 m high). SBG has a Mediterranean climate, with annual rainfall ranging from 453 mm to 596 mm, temperatures often range from 7.4 °C to 27.8 °C (Ramsar 2003).

On a national scale, this site was erected as the Site of Biological and Ecological Interest (SBEI) in 1996. On an international scale, it was designated as a Ramsar site in 1980. SBG was additionally identified by BirdLife International as an Important Bird Area (IBA) in 1999 (Magin 2001). SBG is also classified as a permanent hunting reserve where hunting is strictly prohibited (HCEFLCD 2019). No supplementary feeding is, however, provided to this mammal species in this protected area. SBG is a forested wetland marked by the presence of a dense stand of red juniper (*Juniperus phoenicea* L.) and another, much less dense stand of poplar (*Populus alba*) and oleaster (*Olea europea*). Remarkable shrub species, such as *Retama monosperma, Juncus acutus, Juncus maritimus, Chamaerops humilis, Phillyrea angustifolia* and *Ephedra fragilis*, also occur there.

Although known to be of great importance for waterbirds (Magin 2001), the site of SBG is also crucial for the wild boar, unique representative of large mammals in this forest area.

Data collection. The data on RT selection in the Ramsar site of SBG were collected twice a month between November 2021 and March 2022 along ten transects (Figure 1). Before each field visit, the location of these transects was randomly defined using the QGIS random selection tool (Quantum GIS Development Team 2017). In all visits, the distance between transects was fixed to 350 m (Figure 1). The transect length varied between 250 m and 685 m (mean = 453.21 m ± 25.66 m) according to the forest cover width surrounding the studied wetland. At each passage along the ten transects, we carefully looked for trees with rubbing signs recognized by their relatively whitish scrapped

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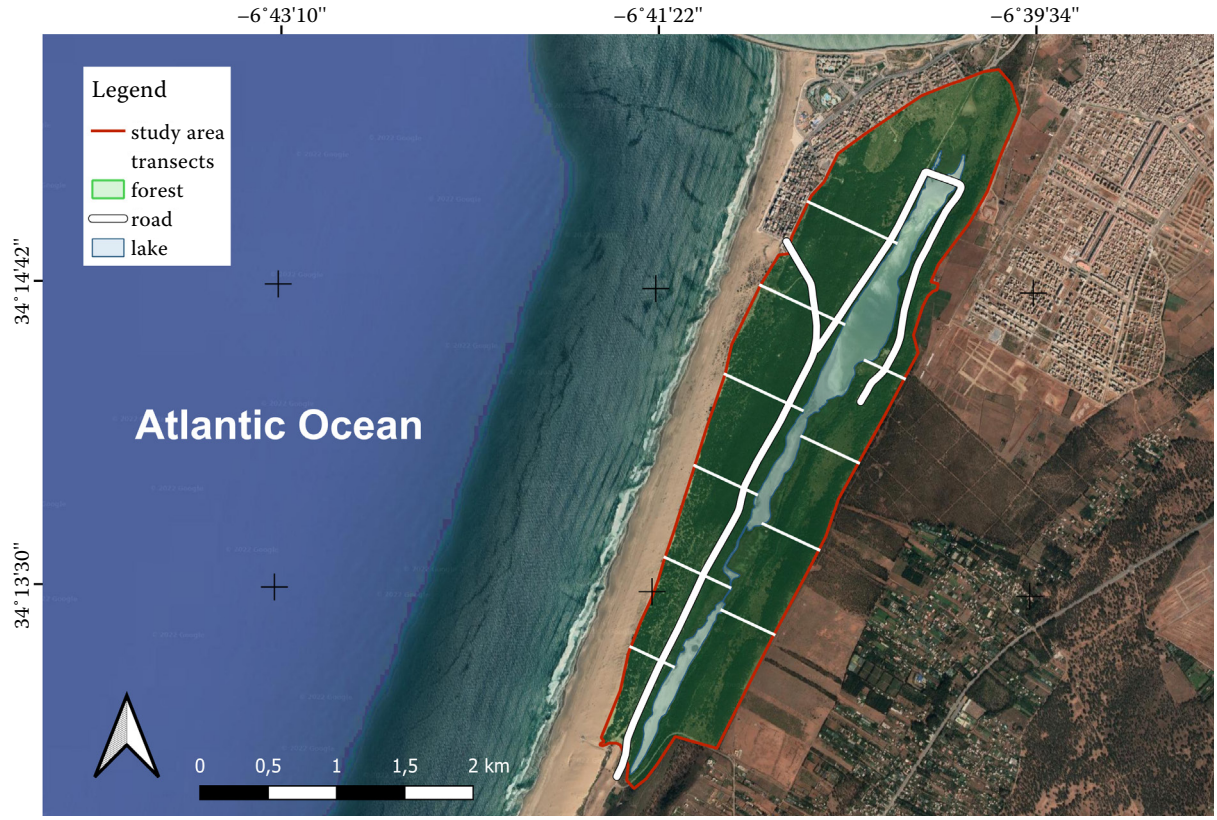

Figure 1. Map showing an example of transects location (the case of first January mission) in the forested Ramsar site of Sidi Boughaba (Morocco)

muddy barks with the presence of wild boar bristles (Figure 2A–C).

After locating a rub tree, we randomly selected, within a 5-m radius around it, a tree with no marking signs (control tree). This radius is commonly used to the extent that it allows sampling of trees having the same local habitat characteristics as the rub trees (Clapham et al. 2013; Gonzalez-Bernardo et al.

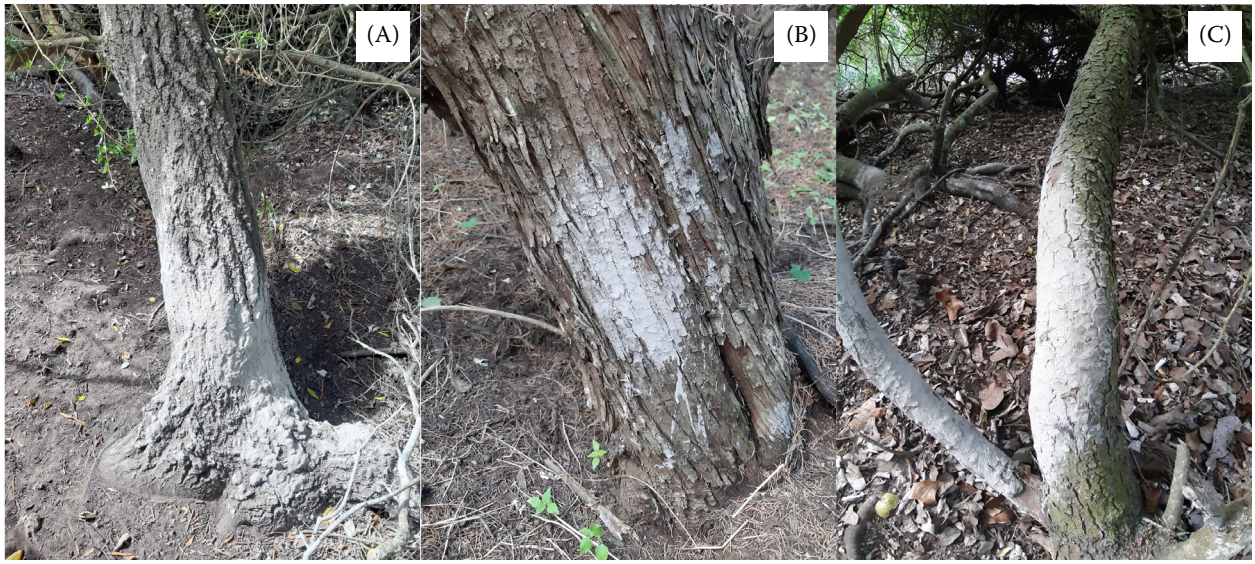

Figure 2. (A–C) Examples of rub trees at the forested site of SBG

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2021). Coordinates of all control and rub trees were recorded using a global positioning system (GPS) device (Garmin eTreex HC; Garmin, USA) (± 3 m).

Explanatory variables. A total of 9 environmental variables related to topography, forest type, microhabitat features, and landscape composition were selected (Table 1). The shrub layer was not included as an explanatory variable because it is exclusively localized in the boundary of the Sidi Boughaba Lake. These variables were used because they can potentially influence the rub tree selection by wild boar (Lee, Lee 2014). The number of trees (*NT*) was counted within circular plots of a 5-m radius (78.5 m^2). Microhabitat variables were collected in the field by the same observer (M. Alaoui) to avoid observer-related biases in vegetation measurements. Variables related to landscape composition were all measured using QGIS (v.3.4.2; 2017). Elevation (m a.s.l.) was determined by a Global Positioning System (GPS), whereas diameter at breast height and distance to the nearest footpath were measured with a tape (± 0.01 m) (Hanane, Besnard 2013). To measure a distance to the nearest wetland, we use the shapefile of the limit of the studied wetland as a polygon in QGIS.

Statistical analyses. Statistical analyses were performed in R software (Version R-4.0.3, 2020). To achieve normality, two independent variables were log-transformed (i.e. the *NT* in a 5-m radius circle and the distance from rub/control trees to the nearest road). To overcome multicollinearity, possible correlations among variables were checked using variance inflation factors (*VIF*s) (Quinn, Keough 2002). Variables with *VIF* > 3 were removed as recommended by Zuur et al. (2010). To evaluate the importance of the three forest tree species for rubbing by wild boar, the chi-squared test was used.

To test the effects of topography, forest type (eucalyptus, poplar, and red juniper), microhabitat features, and landscape composition on the probability of RT occurrence (presence/absence), generalized linear mixed model (GLMM) with a binomial error (logistic regression) was performed using the lme4 package in R (Bates et al. 2015). Plots and transects were included in the model as random factors to reduce the pseudoreplication bias. All

Table 1. Variables used in analysing the occurrences of rub trees by wild boar in the forested Ramsar site of Sidi Boughaba (Morocco)

Class of variable	Variables	Types	Acronym	Description (unit)	Source
Topography	elevation	continuous	*ELV*	height above the sea level (m)	fieldwork
Forest type	trees species	categorical	*TSP*	three modalities (i.e. red juniper, eucalyptus, and poplar)	fieldwork
Microhabitat	diameter at breast height	continuous	*DBH*	diameter of tree trunk at 1.3 m (m)	fieldwork
	proximity to footpath		*DF*	distance from rub/control tree to the nearest footpath (m)	
	number of trees		*NT*	total number of trees in a 5-m radius circle	
Landscape composition	proximity to road	continuous	*DR*	distance from rub/control trees to the nearest road (m)	QGIS v. 3.4.2
	proximity to wetland		*DWT*	distance from rub/control trees to the nearest open water limit (m)	
	proximity to urban area		*DU*	distance from rub/control trees to the nearest urban area (m)	
	proximity to wallow		*DW*	distance from rub/control trees to the nearest wallow (m)	
	proximity to site edge		*DE*	distance to the nearest edge of the site (m)	

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the continuous covariates were considered linearly/log transformed and quadratically transformed (to detect any optimum). An all-inclusive design (all possible combination models) was developed using the Information-Theoretic Approach (Burnham, Anderson 2002). Models were then ordered by increasing the Akaike Information Criterion corrected for small sample sizes using *AICc* (Burnham, Anderson, 2002). All models with Δ*AICc* lower than 2 were considered equally good (Burnham, Anderson, 2002). The explained variance was calculated using the methods of Nakagawa and Schielzeth (2013). Model diagnostics was conducted in the R package DHARMa (Hartig 2020).

To ensure that observations were independent of each other and address spatial autocorrelation, we implemented Moran's index of the residuals of the best models based on AICc to disentangle the roles of (*i*) topography, (*ii*) forest type, (*iii*) microhabitat features, and (*iv*) landscape composition. We used variation partitioning (VP) with an unbiased statistical estimator to ensure the correct interpretation of the results (Legendre 2008). Such an approach aims at identifying which of these four potential predictors is the most relevant in RT selection by wild boars in a forested Mediterranean Ramsar site. In this analysis, we retained only the variables composing the final best *AICc* model with confidence intervals of parameter estimates not encompassing zero. We tested for the significance of each unique fraction using the function rda from the vegan package (Oksanen et al. 2013).

We used the package "car" (Fox, Weisberg 2011) to calculate the VIF, the package MuMIn to calculate *AICc* (Bartoń 2015), and the function r.squaredGLMM to calculate the marginal and conditional R^2. Moran's *I* autocorrelation index was calculated using the package spdep (Paradis et al. 2004). Means are quoted ± standard errors.

RESULTS

In this study, we localized 58 rubbing trees and used other 58 trees with no signs of rubbing as controls. Red juniper accounted for 44.8% of the rubbing trees, eucalyptus for 34.8%, and poplar for 20.7%. No significant difference in using these forest tree species as rubbing trees was recorded (χ^2_2= 5.1034, $P > 0.05$). The average characteristics of rubbing and control trees are summarized in Table 2.

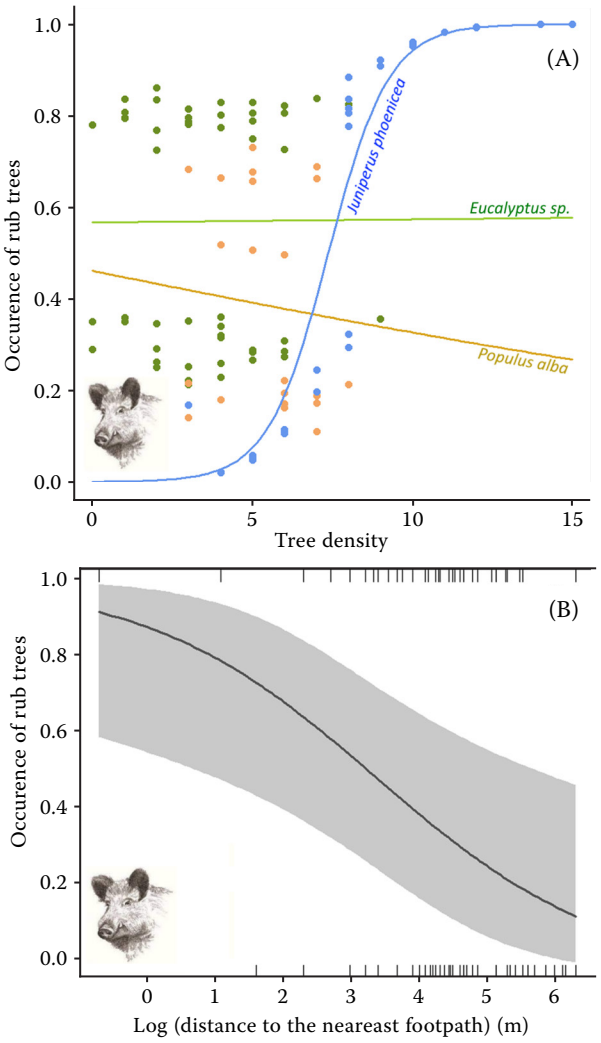

Figure 3. Probability of rub tree occurrence as a function of (A) red juniper, eucalyptus and poplar tree density, and (B) distance to the nearest footpath; the shaded gray areas are the lower and upper 95% confidence limits

The top-ranking model assessing the influence of the nine independent variables showed that the effect of *NT* on RT selection was dependent on tree species (Table 3). Indeed, high RT occurrences were recorded in the dense stands of red juniper (Figure 3A, Table 4). Non-significant patterns of the RT occurrence were noted for eucalyptus and poplar trees (Figure 3A, Table 4), thereby confirming their lower importance in the selection process of rubbing trees by wild boar. At SBG, the probability of RT occurrence decreased with a distance to the nearest footpath, whatever the tree species (Figure 3B, Table 4). We found no evidence of spatial autocorrelation in the residuals of our

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Table 2. Descriptive statistics for variables measured at rubbing trees and control trees in the forested Ramsar site of Sidi Boughaba (Morocco)

Variable	Rubbing trees			Control trees		
	min.	max.	mean ± SE	min.	max.	mean ± SE
ELV	6.60	23.10	13.68 ± 0.52	6.50	23.00	13.51 ± 0.58
DBH	0.15	3.00	0.73 ± 0.06	0.20	2.30	0.70 ± 0.05
DF	0.50	5.50	0.88 ± 0.14	2.51	6.98	1.98 ± 0.20
NT	0.00	15.00	6.14 ± 0.47	0.00	9.00	4.70 ± 0.27
DW	11.45	771.64	80.82 ± 14.84	12.74	235.26	68.16 ± 8.79
DU	329.11	1 271.38	733.55 ± 42.73	375.50	1 207.50	702.89 ± 40.96
DWT	1.15	806.23	143.08 ± 19.27	7.20	840.50	141.74 ± 19.95
DR	4.30	353.30	63.21 ± 8.07	1.41	137.80	55.10 ± 5.39

ELV – elevation; *DBH* – diameter at breast height; *DF* – proximity to footpath; *NT* – number of trees; *DW* – distance to the nearest wallow; *DU* – proximity to urban area; *DWT* – proximity to wetland; *DR* – proximity to road

Table 3. Ten most supported models explaining the RT occurrence by wild boar in the forested Ramsar site of Sidi Boughaba (Morocco); models are ranked according to Akaike's information criterion corrected for small sample size (*AICc*); the degree of freedom (df), difference in *AICc* from the best supported model (Δ*AICc*); Akaike's weights (*wi*); and −2 log-likelihood values (*logLik*) (see Material and methods for details)

Models	df	*logLik*	*AICc*	Δ*AICc*	*wi*
TSP* + log (*DF*) + *NT* + *TSP* × *NT	**8**	**−60.179**	**137.7**	**0.00**	**0.713**
ELV + *TSP* + *DE* + *NT* + *TSP* × *ELV* + *TSP* × *NT*	11	−58.772	142.1	4.40	0.079
ELV + *TSP* + *NT* + *TSP* × *ELV* + *TSP* × *NT*	10	−60.017	142.2	4.44	0.078
TSP + log(*DR*) + *NT* + *TSP* × *NT*	8	−62.583	142.5	4.81	0.064
TSP + *NT* + *TSP* × *NT*	7	−63.804	142.7	4.93	0.060
TSP + log(*DF*) + *NT*	6	−67.606	148.0	10.27	0.004
log(*DF*) + *NT*	4	−71.876	152.1	14.39	0.001
log(*DF*)	3	−73.767	153.8	16.02	0.000
TSP + *NT*	5	−73.249	157.1	19.32	0.000
NT	3	−75.553	157.3	19.59	0.000
Null	2	−79.001	162.1	24.38	0.000

Bold – best models; RT – rub tree; *TSP* – tree species; *DF* – proximity to footpath; *NT* – number of trees; *ELV* – elevation; *DE* –proximity to site edge; *DR* – proximity to road

Table 4. Models parameters (estimate; based on models with Δ*AICc* < 2), standard error (SE) from the best supported model explaining the RT occurrence by wild boar in the forested Ramsar site of Sidi Boughaba (Morocco)

Model	Coeff.	SE	*Z*-value	*P* (> |*z*|)
Intercept	2.503	1.163	2.153	0.0313
log(*DF*)	−0.528	0.215	−2.456	0.0141
Poplar tree	−0.426	1.894	−0.225	0.8222
Red juniper tree	−8.090	2.609	−3.100	0.0019
NT	0.003	0.142	0.019	0.9846
Poplar × *NT*	−0.060	0.332	−0.180	0.8575
Red juniper × *NT*	1.058	0.371	2.854	0.0043

Δ*AICc* – difference in *AICc*; RT – rub trees; *DF* – proximity to footpath; *NT* – number of trees

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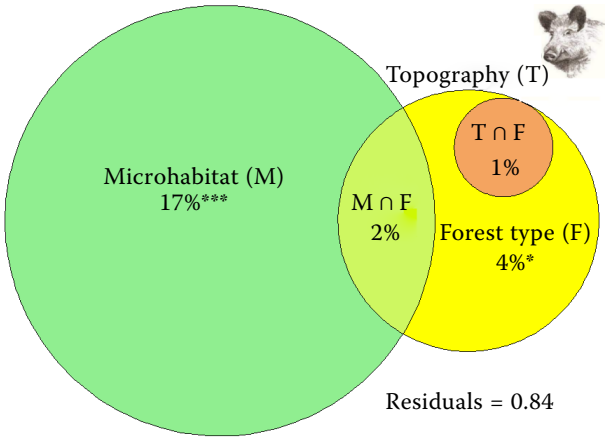

Figure 4. Venn diagram for variation partitioning showing the real contribution of topography, microhabitat, forest type, and landscape composition in explaining RT occurrence in the forested Ramsar site of SBG

*$P < 0.05$; ***$P < 0.001$; RT – rub tree; SBG – Sidi Boughaba

best model *AICc* (Moran's $I = 0.276$, $P > 0.05$), indicating that rub trees are not spatially localized.

The model dispersion test showed no significant overdispersion in the residuals of the *AICc* model (ratio = 1.112, $\chi^2 = 108.10$, *rdf* = 103, $P > 0.05$). The R^2 values (marginal = 0.710, conditional = 0.710) show that about 0% more variance is contributed by forest plots.

The VP analyses revealed that the contribution of the pure fraction of microhabitat (Adj. $R^2 = 0.17$, $F = 11.49$, $P < 0.001$; Figure 4) was very significant, followed, to a lesser degree, by the effect of forest type (Adj. $R^2 = 0.05$, $F = 3.983$, $P < 0.05$; Figure 4). In contrast, the contribution of the pure fraction of landscape composition (Adj. $R^2 = 0.00$, $F = 0.302$, $P > 0.05$) and topography (Adj. $R^2 = 0.00$, $F = 0.380$, $P > 0.05$) was not relevant in explaining RT occurrence.

DISCUSSION

In the present study conducted in the SBG reserve, we investigated the effects of topography, forest type, microhabitat features, and landscape composition on the probability of rubbing trees by the wild boar. To date, most studies on the selection of RT have involved other large mammal species, such as European brown bear (*Ursus arctos*) (Gonzalez-Bernardo et al. 2021), red deer (*Cervus elaphus*) (Charco et al. 2016), and roe deer (*Capreolus capreolus*) (Ramos et al. 2006). To our knowledge, this is the first study that assesses factors affecting the probability of RT occurrences by the wild boar in the Mediterranean region. Our results reveal that this probability depends on the interaction between the density of trees and the three forest tree species being higher in dense trees of red juniper. A high probability of RT presence is also recorded in the proximity of footpaths, whatever the forest type. This work will help understand rub tree selection processes by wild boars in this forested Mediterranean Ramsar site.

The highest RT occurrences are recorded in high red juniper tree density corroborating our hypothesis (*i*). The choice of such a forest environment would be due to its difficulty of penetration for humans and cattle. A great use of dense forest patches by wild boars has been recorded by several previous studies, such as Keuling et al. (2009) in Germany, Luskin et al. (2021) and Khalidah et al. (2021) in Malaysia, and Karami and Tavakoli (2022) in Iran. Overall, the selection of dense trees of red juniper for rubbing could be an adaptation strategy used to cope with human presence in the Ramsar site of SBG, while ensuring protection against possible predators (in our case, stray dogs), as stated recently by Barasona et al. (2021) and Karami and Tavakoli (2022). The high sensitivity of wild boars to human disturbance has been reported by several studies, namely Ikeda et al. (2019), and Johann et al. (2020).

Consistent with our hypothesis (*i*), the occurrence of RT increases in the close proximity of footpaths, whatever the forest type. Such behaviour is not surprising since the species is known to seek narrow trails for relatively easy navigation (Luskin et al. 2021). Furthermore, contrary to Sardin and Cargnelutti (1987), our statistical analyses do not raise a significant effect of diameter at breast height to predict RT occurrence, thus confirming that, at the site of SBG, the selection of trees for rubbing is, first of all, a matter of safety.

The VP results evidence the robustness of microhabitat features in explaining RT occurrence (17%), followed by forest type (only 5%). Contrary to hypothesis (*ii*), the other components (i.e. topography and landscape composition) are not relevant to explain the probability of RT. For instance, the spatial dissociation often recorded between the location of rub trees and wallows (Dardaillon 1984; Sardin, Cargnelutti 1987) does not permit the emergence of a possible effect of the landscape composition. Likewise, the altitudes of both rub and control trees belong to the same slice (from 6.5 m to 23.0 m), not allowing highlighting a significant effect of topography.

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CONCLUSION

In short, our results suggest that the RT occurrence depends on the density of red juniper trees and the distance to the nearest footpaths. Such specific features of the forest microhabitat are, therefore, essential for wild boars of SBG. To make these microhabitat characteristics available, it would be beneficial to keep the red juniper forest of SBG as far away from humans as possible, by prohibiting its access.

Moreover, it is worth mentioning that our model explained only 14% of RT occurrence in this forested Ramsar site. These results suggest that there are yet several other non-evaluated covariates which may influence the occurrence of RT in SBG. Our results highlight the need to undertake future works to understand the bio-ecology of this mammal species in this internationally important site. Research should primarily focus on (*i*) assessing the real impact of rubbing on the health of forest trees, and (*ii*) striking a balance between, on the one hand, the availability of forest trees and, on the other, the pressure exerted by wild boars. It is also recommended to test the geographical generality of our results using the same analytical approach in other forests of the Mediterranean basin.

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