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Regional relationship between red deer population density and forest stand in Türkmenbaba Wildlife Development Area, Kütahya

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Abstract: In Türkiye, the red deer (*Cervus elaphus* L., 1758) is one such species that has been under protection in various regions due to its declining population for many years. The aim of this study is to estimate the population size of red deer in the Türkmenbaba Wildlife Development Area (TWDA) and to determine the regional relationship between population density map and forest stand map. The study area was used to estimate the population density of red deer by carrying out pellet group counts in 80 sample areas using the Fecal Standing Crop (FSC) method. The density data was used to obtain a density map through the Inverse Distance Weighted tool in the ArcGIS program. According to the FSC, an average of 2.125 ± 0.246 pellet groups were counted, resulting in a pellet group density of 17.71 ± 2.05 per hectare. The estimated red deer population density for the TWDA was 0.999 ± 0.116 individuals per km², with a total estimated population of 118.77 ± 13.75. The study show that areas with high and very high red deer population density cover 5.06% of TWDA. Based on each stand type, these areas have mostly degraded scots pine and forests where oriental beech is dominant. Areas without red deer cover 36.05% of TWDA and contain many settlements, coniferous forests and forests where oak is dominant. The results of this study can contribute to managers and researchers in explaining to relationship between population size and forest stand in red deer wildlife development areas.
Keywords: Forest stand map, Pellet group count, Population density, Red deer, Türkiye

Kütahya Türkmenbaba Yaban Hayatı Geliştirme Sahası'nda kızılgeyik popülasyon yoğunluğu ile meşcere arasındaki bölgesel ilişki

Öz: Türkiye'de Kızılgeyik (*Cervus elaphus* L., 1758) uzun yıllardır popülasyonu azaldığı için çeşitli bölgelerde koruma altına alınmış bir türdür. Bu çalışmanın amacı Türkmenbaba Yaban Hayatı Geliştirme Sahası'ndaki (YHGS) Kızılgeyik popülasyon büyüklüğünü tahmin etmek ve popülasyon yoğunluk haritası ile meşcere haritası arasındaki bölgesel ilişkiyi belirlemektir. Çalışma alanında, Dışkı Kalan Ürün (FSC) yöntemi kullanılarak 80 örnek alanda dışkı grup sayımları yapılarak Kızılgeyik popülasyon yoğunluğu tahmin edilmiştir. Yoğunluk verileri ArcGIS programındaki Inverse Distance Weighted (IDW) aracı ile yoğunluk haritası elde etmek için kullanılmıştır. FSC'ye göre, hektar başına ortalama 2,125 ± 0,246 dışkı grubu sayılmış ve hektar başına 17,71 ± 2,05 dışkı grup yoğunluğu elde edilmiştir. YHGS için tahmini Kızılgeyik popülasyon yoğunluğu km² başına 0,999 ± 0,116 birey, tahmini toplam popülasyon ise 118,77 ± 13,75'tir. Çalışma, yüksek ve çok yüksek Kızılgeyik popülasyon yoğunluğuna sahip alanların YHGS'nin %5,06'sını kapladığını göstermektedir. Her ormanlık alan türüne göre, bu alanlar çoğunlukla bozulmuş sarıçam ve doğu kayınının baskın olduğu ormanlardır. Kızılgeyiğin olmadığı alanlar YHGS'nin %36,05'ini kaplar ve birçok yerleşim yeri, iğne yapraklı ormanlar ve meşenin baskın olduğu ormanları içermektedir. Bu çalışmanın sonuçları, yöneticilere ve araştırmacılara Kızılgeyik yaban hayatı geliştirme sahalarındaki popülasyon büyüklüğü ve meşcere arasındaki ilişkiyi açıklamada katkıda bulunabilir.
Anahtar kelimeler: Meşcere haritası, Dışkı grup sayımı, Popülasyon yoğunluğu, Kızılgeyik, Türkiye

1. Introduction

Türkiye is a country rich in biological diversity, with a diverse climate structure, wildlife, and plant diversity. This is attributed to the intersection of the world's biodiversity hotspots, the European Siberian, Irano-Turanian, and Mediterranean phytogeographic regions, over our country (Demirsoy, 1996). Türkiye occupies a very important position, especially on a European scale, due to its high large mammal species richness (Morrison et al., 2007). Indeed, about 171 of the approximately 200 mammalian species found in Europe are found in our country. However, it is a known fact that today many wildlife species are extinct, and many are facing the threat of extinction (Oğurlu, 2003).

Monitoring the development of the population, taking appropriate conservation and management measures to neutralize adverse factors, preparing a more favorable development ground, or controlling growth when necessary are important aspects of inventory. In other words, inventory provides the most significant contribution to measuring the success of planning and conservation activities related to operation and utilization (Oğurlu, 2003).

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Estimates of deer population generally rely on direct and indirect methods (Alves et al., 2013). Direct counting methods require visual observation of individuals, which can provide information about population structure and behaviors in addition to their numbers. However, these methods are time-consuming, expensive, and not practical for implementation in large areas, and are limited to specific sampling periods and areas (Smart et al., 2004). Therefore, indirect counting methods have been developed as an alternative to direct counting techniques. This method is usually based on fecal group counts, assuming that each animal leaves signs of its presence (Putman, 1984; Mayle et al., 1999; Mandujano, 2014).

Fecal Pellet Counts (FPC) first emerged in the late 1930s with people counting deer groups (McCutchen, 1938) and developed into fecal counts in 1940 (Bennett et al., 1940; Alves et al., 2013). FPC is an indirect method used to estimate the density of an animal population from pellets on the ground. With the number of observed pellets, decay times, and the defecation rate of the target animal species, it is possible to obtain an accurate and precise density estimate. Thus, with FPC, deer population distributions, trends, habitat preferences, and seasonal changes in habitat use patterns are evaluated (Putman, 1984).

The main techniques used to estimate deer abundance with fecal counts from indirect methods are Fecal Standing Crop (FSC) and Fecal Accumulation Rate (FAR). Many researchers have investigated the working principles of these two techniques (Staines and Ratcliffe, 1987; Mayle and Staines, 1998; Laing et al., 2003; Smart et al., 2004; Forsyth et al., 2007). While FSC is estimated by counting the number of fecal groups accumulated in random sample areas, these data are then converted into estimates of deer population size and population density by applying specific deer defecation rates and fecal persistence times. FAR is measured by initially cleaning all deer pellets from the sample areas and then recounting after a fixed period to determine the number of pellet groups accumulated during this period (Mayle and Staines, 1998). So, each sample area requires two visits with FAR and one visit with FSC, and for density estimation, only the defecation rate is needed for FAR and both the defecation rate and decay time are needed for FSC (Mayle et al., 1999).

Defecation rate is the number of pellet groups produced by an animal in a day. Decay time is the number of days pellets take to decompose. A pellet group is defined as six or more pellets from the same defecation. (Mayle et al., 1999). The defecation rate and decay time can vary depending on the animal species, feeding style, climate conditions (precipitation and temperature), habitat, and the presence of invertebrate fauna in the field (Neff, 1968; Mayle et al., 1999).

The FPC method was used to estimate the population size of the red deer, one of the most important wildlife species in Türkiye, in the Eskişehir-Çatacık WDA (Oğurlu, 1997) and Afyonkarahisar-Akdağ WDA (Koca, 2021). Generally, the most cost-effective and efficient method to estimate deer numbers through pellet counts is FSC, especially in small populations (Laing et al., 2003; Alves et al., 2013). This study aims to estimate the population size of the red deer, the target species in the Türkmenbaba Wildlife Development Area (TWDA), using the pellet group count, an indirect counting method, to obtain a population density map and to carry out an analysis of forest stand map. For this purpose, it is important to use a different sampling design for FSC and the decay time of red deer pellets in the Kütahya-TWDA. This study is expected to contribute to the estimates of the relevant institutions of the Republic of Türkiye Ministry of Agriculture and Forestry who conduct studies to determine the population density of red deer in our country.

2. Materials and methods

2.1. Study area

There are 85 Wildlife Development Areas in Türkiye, and the target species in 19 of them is the red deer. One of these 19 areas is the TWDA, located within the borders of Kütahya and Eskişehir provinces (39º 23’ - 39º 34’ north latitudes and 30º 14’ - 30º 23’ east longitudes) (Figure 1). The TWDA was declared on 5 October 2006, and has been protected by the Republic of Türkiye Ministry of Agriculture and Forestry. The protection of the area is the responsibility of the General Directorate of Nature Conservation and National Parks affiliated with this Ministry. The study area, which has an area of 11888 hectares, has an elevation varying from 790 to 1825 m (NCNP, 2023). The annual average temperature of the study area and its surroundings is 10.8°C, and the annual average precipitation is 562.2 mm (TSMS, 2023).

The most widely distributed primary tree species on Türkmen Mountain are Anatolian black pine (*Pinus nigra* subsp. *pallasiana*) and Scots pine (*Pinus sylvestris*). There are oak species (*Quercus* spp.) and oriental beech (*Fagus orientalis*) stands. When looking at the stand map of the study area, it is observed that Scots pine, black pine, oak and beech trees dominate the area as degraded, pure or mixed forests. The mass of Türkmen Mountain consists mainly of rhyolite and dacite bedrock (Güner, 2006).

2.2. Methods

The field study carried out between 2021 and 2022, covering distinct seasonal periods to account for temporal variations in red deer habitat use. We counted pellet groups in 80 sample areas (240 plots) to estimate the population density of red deer. The coordinates of the center points of the 80 randomly placed sample areas were recorded in Excel format, and a handheld GPS (Global Positioning System) was used to locate these points in the study area. The sample areas were distributed across the terrain while carefully considering spatial variations in habitat characteristics (Aksan et al., 2014; Ertuğul et al., 2017). Within these sample areas, plots were systematically arranged to ensure representative coverage of the study area. The centre of the other plots are 52 m far from the centre of sample area. The locations of 240 plots (20x20m) and 80 sample areas (100x100m) are given in Figure 2.

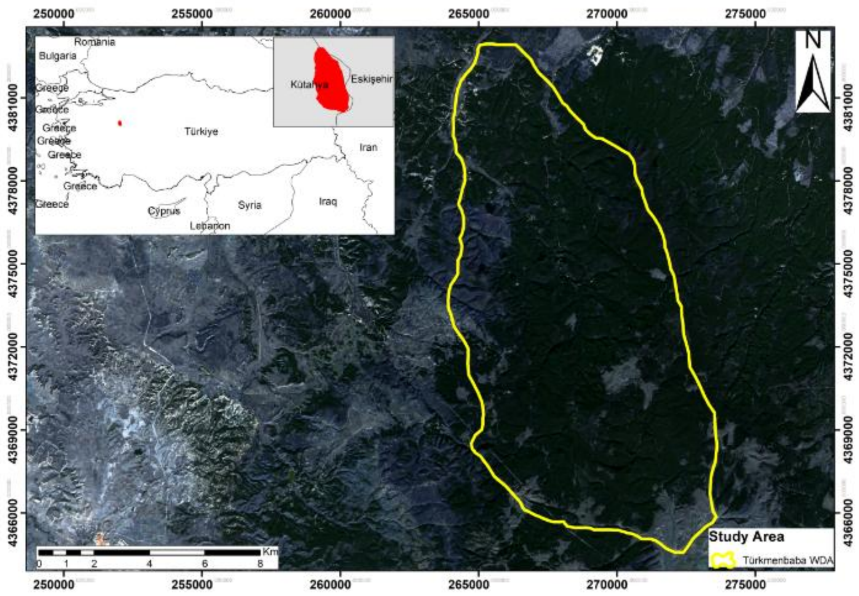

Figure 1. Study area of Türkmenbaba WDA, Kütahya

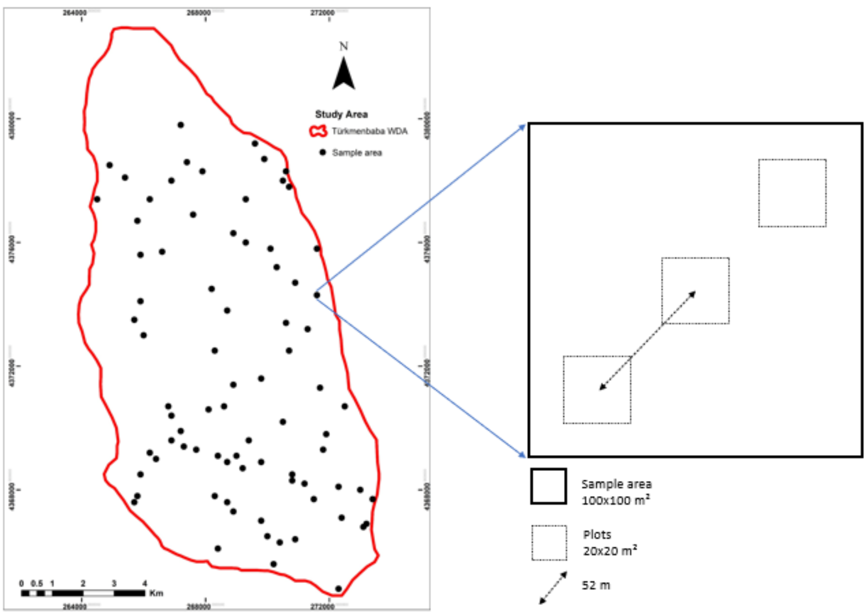

Figure 2. Sample desing and size for red deer pellet group count in Türkmenbaba WDA, 2023

Pellet groups were counted in an area of 1200 m² per hectare, given that the plot size is 400 m². All plots were scanned for pellets, including under leaves and grasses. These pellet group counts were converted into pellet group densities and used to determine the population density of red deer in the TWDA. In order to estimate the population density of red deer, the pellet group densities in the plots were calculated using Eq. 1.

$$Dpg = \frac{n}{a} \tag{1}$$

where (*Dpg*) the pellet group density is found by dividing the number of pellet groups (*n*) by the sample area (*a*). The sample areas were calculated in m², and then the dropping densities were determined per km².

In the TWDA, the formula in Eq. 2. was used to find the red deer population density (*D*) per km² (Smart 2004).

$$D = \frac{Dpg}{dt*dr} \tag{2}$$

where, the defecation rate (*dt*) represents the number of pellets a deer produces in a day (number of pellets/day), and the decay rate (*dr*) represents the time elapsed from the cleaning of the sample areas to the second count, or the decay rate (days). The decay rate has been taken into account in the FSC method of calculation.

Since the direct measurement of the pellet decay rate requires long-term field monitoring and intensive labor (Laing et al., 2003), we considered it appropriate to use values obtained from previous studies conducted under similar conditions for this study. Specifically, we referenced the 141.8-day decay rate calculated for red deer in Golestan National Park, Iran (Soofi et al., 2017), which closely resembles our study area in terms of climate, habitat structure and elevation. Additionally, the average of the 92 days (Oğurlu, 2001) and 196 days (Oğurlu, 1997) values reported in previous studies conducted in Türkiye, which is 144 days, is consistent with the data from Iran. Therefore, considering the consistency of the existing literature and practical constraints, we decided that this approach is valid instead of conducting direct measurements. The defecation rate, which is 12.5 (Neff, 1968), was used for the red deer population density in the Eskişehir-Çatacık WDA (Oğurlu and Yavuz, 1994). This defecation rate (12.5) was taken into account because the study area is similar characteristics and very close to Eskişehir.

The estimated total number of deer (*N*) in the area was calculated by multiplying total area (*A*) of TWDA by the red deer population density (*D*) of the TWDA. (Eq. 3).

$$N = A * D \tag{3}$$

For the TWDA, a red deer population density map was obtained in the ArcGIS program using the 'spatial analyst' tool with density data per km². In this tool, population density map was created by interpolationing from red deer density points using an inverse distance weighted (IDW) technique. The accuracy of the produced map can be evaluated with ROC and AUC (Yılmaz, 2023). In order to estimate the accuracy of red deer density map, the ROC function in the ArcSDM tool, which can be added to the ArcGIS programme, was used. In the accuracy estimation, pellet data found in 50 sample areas were used. This map was then converted into polygons in 5 classes (manual method) and evaluated with the forest stand map. The spatial distribution of all forest stand types in polygons was analysed. The forest stand type classification has been made as coniferous, deciduous, mixed, degraded forest, forest openings, agricultural, power line and settlement areas. After all, the red deer population density classes were regionally associated with these forest stand classes.

3. Results

In this study, the Faecal Standing Crop (FSC) method, an indirect counting method, was used to estimate the red deer population density. The study was carried out in one of the important protected areas in Türkiye, the TWDA, where the red deer pellet group density was calculated in 80 sample areas (240 plots) to estimate the population density of the area. A map of red deer population density for the TWDA was obtained and used in the analysis of forest stand map.

According to the pellet group counts carried out in the sample areas, a total of 170 pellet groups were counted, with a maximum of 8 pellet groups per plot. An average of 2.125±0.246 fecal groups were found in 80 sample areas. No red deer pellets were found in 30 sample areas. In other words, no pellets were found in 135 of the total 240 plots, with an average of 0.708±0.082 pellet groups found in the plots. Also, an average of 21 pellets were detected in one plot.

In TWDA, the red deer defecation rate of 12.5 and the fecal decay rate of 141.8 days were used. The fecal group density was calculated as 17.71±2.05 per hectare. Thus, the average red deer population density in TWDA was estimated as 0.999±0.116 per km². It is estimated that there are a total of 118.77±13.75 individual in the area, which is 118.88 km² in size.

The red deer population density map for TWDA (Figure 3a) was obtained in the ArcGIS program by entering the density data per km² numerically into the sample areas. In order to conduct stand map analysis with the red deer population density map, the stand map of TWDA was prepared by combining the maps obtained from relevant institutions of Ministry of Agriculture and Forestry (Figure 3b).

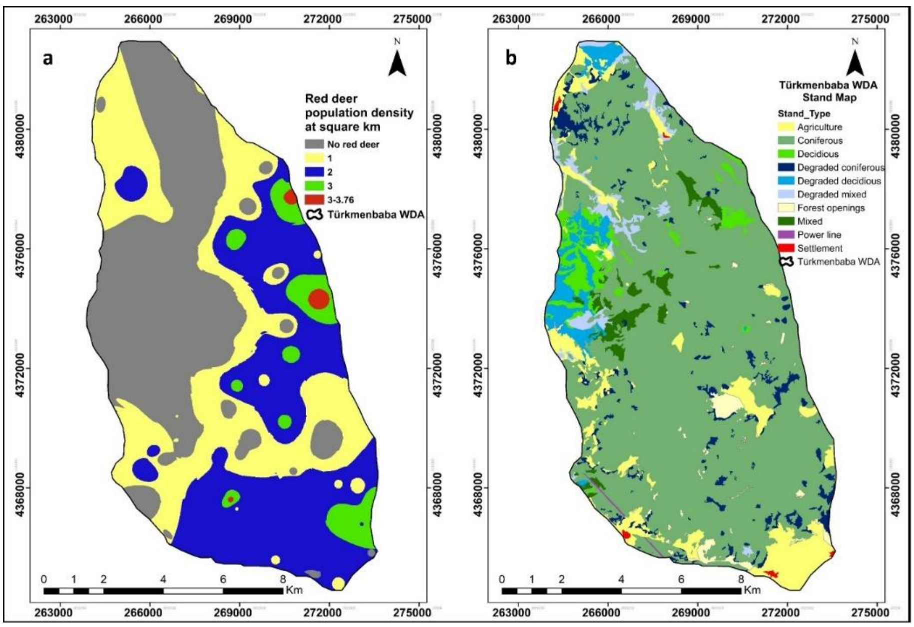

Figure 3. a) The red deer population density map for TWDA b) Stand map of TWDA

According Figure 3a, it is observed that the density of red deer increases in the south and east of the area. As you move north and west of the area, the density of red deer decreases. Table 1 shows red deer population density has five classes as density and percentage of total area.

The accuracy analysis of the red deer population density map was carried out with the 'ROC' tool in ArcGIS environment. The area under the curve was 97.5% and it was seen that the prediction was quite high (Figure 4).

Stand map classification has been made as coniferous (black pine, scots pine and combined them), deciduous (oak, beech and combined them), mixed (coniferous and deciduous), degraded forest (coniferous, deciduous and mixed), forest openings, agricultural, power line and settlement areas. This classification is shown in Table 2, along with the percentage of area covered by each category.

In TWDA, coniferous cover the largest area, forming an area of 8633 ha, while the forest area with a degraded structure is 1230 ha, the forest area formed by deciduous species is 402 ha, the forest area formed by mixed species is 328 ha, the agricultural area is 1062 ha, the forest openings is 196 ha, power line area is 13.7 ha, and the settlement covers an area of 36 ha. The area covered by conifers in the field is 72.6% (Table 2.), and these conifers consist of 33.8% pure black pine, 15.2% pure scots pine, and 23.6% mixed forest of black pine and scots pine.

In Table 3, the percentage of the area covered by stand types in TWDA is given in areas where red deer population high and very high density. There are mostly degraded scots pine (32.37%), mixed forest of scots pine and oriental beech (31.11%) and pure oriental beech forest (21.70%) in these areas.

In Table 4, the percentage of the area covered by stand types in TWDA is given in areas where no red deer. In these areas, there are mostly degraded oak stands (94.14%), settlement areas (93.88%), pure oak stand (85.54%), coniferous (87.96%) and stands where oak is combined.

Table 1. Red deer population density as percentage of area in TWDA and density classes

Red deer population density (per km²)	Density Class	Total Area of TWDA (%)
0	No Red Deer	36.05
1	Low	28
1-2	Medium	30.79
2-3	High	4.68
3-3.76	Very High	0.48

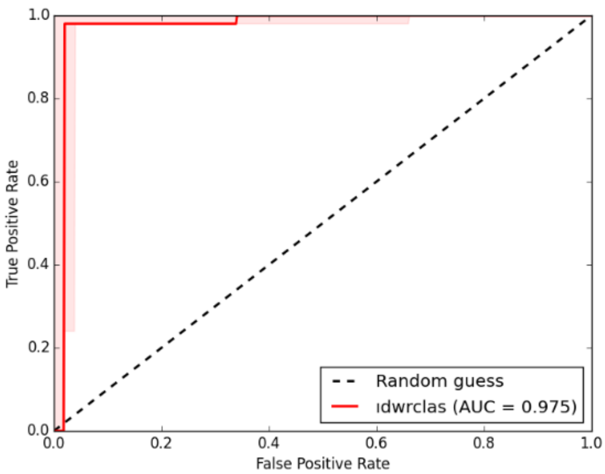

Figure 4. Accuracy analysis of red deer population density map

Table 2. Percentage of stand types in TWDA

Stand types	Total area of TWDA (%)
Coniferous	72.62
Degraded forest	10.34
Agriculture	8.94
Decidious	3.38
Mixed	2.76
Forest openings	1.65
Settlement	0.19
Power line	0.12

Table 3. Percentage of TWDA stand types in areas where red deer population high and very high density

Stand types	Total area of stand (%)	Stand types	Total area of stand (%)
Agriculture	5.71	Agriculture	5.71
Black pine	2.69		
Black pine and scots pine	9.46	Coniferous	15.95
Scots pine	3.80		
Degraded black pine	13.40		
Degraded black pine and scots pine	7.67	Degraded coniferous	53.44
Degraded scots pine	32.37		
Forest openings	7.48	Forest openings	7.48
Oriental beech	21.70	Decidious	21.70
Scots pine and oriental beech	31.11	Mixed	31.11

Table 4. Percentage of TWDA stand types in areas where no red deer

Stand types	Total area of stand (%)	Stand types	Total area of stand (%)
Agriculture	25.75	Agriculture	25.75
Black pine	42.91	Coniferous	87.96
Black pine and scots pine	21.36		
Scots pine	23.69		
Oak	85.54	Decidious	95.22
Oriental beech	9.68		
Degraded black pine	22.95	Degraded coniferous	46.59
Degraded black pine and scots pine	13.17		
Degraded scots pine	10.47		
Degraded oak	94.14	Degraded decidious	94.14
Degraded black pine and oak	68.34	Degraded mixed	68.34
Forest openings	7.07	Forest openings	7.07
Black pine and oak	76.77	Mixed	76.77
Settlement	93.88	Settlement	93.88
Power line	37.75	Power line	37.75

4. Discussion

Wildlife managers have reported an increasing importance of pellet counts (Neff, 1968; Smart et al., 2004; Acevedo et al., 2010; Alves et al., 2013), one of the indirect counting methods used to estimate animal abundance, and that factors such as estimating pellet group abundance, determining defecation rate, and estimating decay rate are effective in these pellet group counts. They have tried to solve this problem with a function they obtained from logistic regression, as the factor they see as the biggest problem is the estimation of fecal decay rates. So it is predicted that finding the average time until pellet decay rate will give more accurate results in estimating population abundance (Laing et al., 2003).

Since pellet decay rates can vary between habitats, future studies should investigate the use of a site-specific value for each dominant habitat instead of an average value (Mayle et al., 1999).

Our study demonstrates the successful application of pellet group counting, an indirect method. This study, which can be implemented by anyone at any time of the year and is inexpensive, has provided information about red deer density over a wide area, including dense forests like TWDA, with advantages such as significant time and lower costs.

In our study, a value of 141.8 was used for the red deer pellet decay rate. It has been observed that the values used for deer pellet decay rate in different regions are; 150, 136 and 264 days (Smith, 1964), an average of 227 days (Torres et al., 2013), 60 days and 150 days (Smart et al., 2004), 136 days (Batcheler, 1975). In Türkiye, the pellet decay rate of red deer has been used as 92 days (Oğurlu, 2001) and 196 days (Oğurlu, 1997). For our study area, when the red deer defecation rate is kept constant and the decay rate is taken as 92 days, the deer density is calculated as 1.54 per km² and the total estimated 183 individual in TWDA. When the decay rate is taken as 150 days, the deer density is 0.944 per km² and there are an estimated total of 112 individual in TWDA. When the decay rate is taken as 196 days, the deer density is 0.72 per km² and there are an estimated total of 86 individual in TWDA. According to the 2023 inventory data of the General Directorate of Nature Conservation and National Parks (NCNP, 2023), there are 238 red deer present in the area. There is a need to determine pellet decay rates across different habitat types, as variations in these rates can directly influence estimates of red deer population density. Accurate assessment of decomposition rates is important to ensure reliable interpretations of pellet-based abundance indices.

In our study, a value of 12.5, which was used in Türkiye and in a field very close to our study area, was given for the red deer defecation rate. Smith (1964) researched the average defecation rate in pellet group counts he carried out over three winters. He determined the average daily pellet group drop number as 13.2 in fawn, young and mature deer (*Odocoileus hemionus*) feeding in the natural environment. There is also a study stating that the average daily deer defecation rate is 12.7 (Eberhardt and Van Etten, 1956).

In order to have more accurate results when counting pellet groups in Türkiye, which is one of the indirect methods of red deer population density, it is necessary to have statistical data on the defecation and decay rate values. This is important in order to provide comparative data.

When estimating red deer population densities, FAR and FSC methods are used. While FAR is measured by re-sampling after a fixed period to determine the number of pellet groups accumulated during this period, after all pellets are cleaned from the sample areas at the beginning, no cleaning is done in FSC. A comparative study has proven that FSC provides more accurate population estimates and performs better than FAR (Smart et al., 2004). It is also reported in the literature that the FSC method is more efficient than the FAR method (Smart et al., 2004; Acevedo et al., 2010; Camargo-Sanabria and Mandujano, 2011; Alves et al., 2013). In Türkiye, the red deer population density with pellet group counting has been estimated as 2.01 per km² in Çatacık WDA (Oğurlu, 1997) and 1.95 and 1.98 in Akdağ WDA (Koca, 2021). In our study, the red deer population density in Türkmenbaba WDA was estimated to be 0.999 per km² using the FSC method. Subsequently, a map of red deer density for the area was obtained.

Türkmenbaba WDA has low deer density in the scale of our study. However, when looked at on a world scale, it is seen that the density is lower. According to Smart et al. (2004), the density scale of the red deer population is not known with certainty. That's why they generally use the estimates based on hunting data to classify each area into three deer density classes: high, medium and low: > 5 ind./100 ha, 2–5 ind./100 ha and < 2 ind./100 ha respectively. Acevedo et al. (2008) reported to the low-middle density (<20.00 ind/100 ha) and high density (>20.00 ind/100 ha) in mediterranean habitats. Perea et al. (2014) reported the high deer density as ≥30 deer /100 ha.

In this study, the red deer population size was estimated using population density data for the entire area. For future studies, it is recommended to exclude non-habitable areas for the species (e.g., settlements, water areas) from the total area by utilizing habitat suitability maps. Accordingly, population size estimates should be based on the effective habitat area, taking into account factors such as habitat characteristics and species-specific space use.

Understanding trends in population size is beneficial for sustainable management planning. In fact, long-term monitoring programs should provide information about population trends, habitat requirements, the impacts of anthropogenic activities, and the damages caused by species to agriculture and forestry, rather than just focusing on the number of individuals in a population. This is particularly important when dealing with species like deer, which have a significant economic impact on human societies (Morellet et al., 2010).

Since WDA in our country are generally located in forested areas, wildlife management has a close relationship with the planning of forest resources. In order to effectively utilize forest resources and guide wildlife conservation efforts, it is necessary to include stand maps along with population density maps.

The red deer density map was associated with spatial distribution of forest stand map in TWDA. In areas where red deer population high and very high density cover mostly degraded coniferous stands, particularly degraded scots pine as total stand types areas. These areas have no settlemet and few agriculture areas. Indeed, it is reported that young scots pine forests (Härkönen and Heikkilä, 1999) far from settlement areas (Oruç, 2017; Süel and Ercan, 2019) and scots pine and black pine mixed forests (Oruç, 2017) are preferred by red deer. It also tends to avoid areas with human disturbance (Keten and Kahraman, 2019). Areas where no red deer individual cover mostly settlement, pure coniferous, degraded, mixed and pure oak forests as total stand types areas. Black pine forest have the most area in here for areas where no red deer. This study examined the relationship between red deer and stand types; however, it did not address the association between red deer and broader habitat types. Nonetheless, the findings provide a valuable foundation for the development of habitat suitability models for red deer in future research. In this way, the study contributes to the fundamental components of wildlife for understanding of population ecology.

Finally, the results of this study using a single method and a single area for red deer in Türkiye should be compared with different regions and different methods. This study is considered valuable because there are few studies using pellet group counts to estimate red deer population density in Türkiye. In addition, even if different pellet decay and defecation rates are used in this study, the fact remains that deer are more abundant in degraded scots pine and beech dominated forests than in degraded oak forests and settlements.

In this regional relationship of forest stand map, explanations were made by considering the spatial distribution of deer densities rather than the habitat preferences of red deer. For effective planning, it is necessary to monitor the red deer population density in TWDA and identify suitable habitats.

5. Conclusions

Pellet decay and defecation rates may be used regionally to estimate red deer population size in areas with similar characteristics to our study area. Replicating this study in different regions of Türkiye and under different conditions may help to overcome the methodological limitations. The results of this study can contribute to managers and researchers in explaining the relationship between population size and forest stand in red deer wildlife development areas. To inform future research, red deer density should be investigated in relation to stand characteristics such as canopy closure, age, and diameter, as well as proximity to roads, water sources, or human settlements. Incorporating these variables will enhance the ecological interpretation of red deer distribution patterns. For effective red deer management, in addition to population density, it is necessary to determine the habitat preferences of red deer.

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