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Impact of forest fragmentation on the distribution of elephants (*Loxodonta africana*) in the N'Zi Supérieur Classified Forest, Côte d'Ivoire

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Abstract

The N'Zi Supérieur Classified Forest (NSCF) is one of the last refuges of the savanna elephant (Loxodonta africana) in northern Côte d'Ivoire. This study aimed to assess the influence of anthropogenic pressure on the spatial distribution of the species within this ecosystem. Presence indices (droppings, footprints, feeding traces) and anthropogenic activities (agriculture, transhumance, land clearing, logging, campsites, hunting, and pollution) were recorded along seven transects and reconnaissance walks. Data were analyzed using dot mapping and spatial interpolation (IDW) with QGIS 3.16.11. Results indicate a high concentration of elephants in the north-eastern sector, near watercourses and areas with low human disturbance, while anthropogenic pressures are widespread, with hotspots in the centre and north of the forest. These findings suggest that human activities restrict the species' dispersal and confine its presence to limited refuges. The study underscores the need for sustainable management combining strict protection of refuge areas and regulation of anthropogenic activities in order to preserve the savanna elephant and the biodiversity of the NSCF.

Keywords: Savanna elephant; N'Zi Supérieur Classified Forest; Anthropogenic pressures; Spatial distribution; Conservation

1. Introduction

Ivory Coast's forest cover has been continuously declining due to anthropogenic activities, despite conservation efforts [1–3]. This degradation leads to a progressive loss of natural habitats, forcing wildlife to retreat into remaining protected forest fragments [4–6]. Within these areas, wildlife in general — and elephants in particular — play a major ecological role. This species contributes to the maintenance of forest ecosystem balance through seed dispersal and regeneration activities [4, 7–9]. Studies conducted in Taï National Park have highlighted the close interrelationships between elephants and vegetation, suggesting that the disappearance of one could jeopardize the survival of the other [10–12]. Furthermore, Soulemane [13] and Kouamé [9] demonstrated that the forest elephant (

Loxodonta cyclotis) plays a significant role in the dispersal of large tropical tree species such as *Tieghemella heckelii*, *Sacoglottis gabonensis*, *Parnaria excelsa*, and *Balanites wilsoniana*. As seed dispersal is an essential process for maintaining plant diversity, the disappearance of this iconic species would pose a serious threat to many plant and animal species that depend on it [14]. Given its ecological importance, the development of a sustainable elephant population management plan appears essential for the benefit of managers, local communities, and future generations. It is in this context that the present study was conducted in the N'Zi Supérieur Classified Forest (NSCF), one of the last refuges of the species in northern Côte d'Ivoire. It aims to assess the influence of anthropogenic pressure on the

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distribution of the savanna elephant (*Loxodonta africana*) in this forest and to propose appropriate sustainable management strategies.

2. Material and Methods

2.1. Study Site

Located in northern Côte d'Ivoire, the N'Zi Supérieur Classified Forest covers approximately 95,000 hectares between the sub-prefectures of Tafiré and Kong. Geographically, the NSCF lies between longitudes 4° and 7° East and latitudes 8° and 11° North [15] (Figure 1). The regional climate is tropical, characterized by the alternation of four seasons: two rainy and two dry seasons [16]. The mean annual temperature is approximately 28°C [17], while mean annual rainfall reaches nearly 1,200 mm [18]. Hydrologically, the NSCF belongs to the watershed of the Bandama River and its main tributary, the N'Zi, which crosses it and gives it its name [19, 20]. It occupies the northern part of the "V Baoulé" and harbors a mosaic of ecosystems comprising savanna formations, forested areas, and agricultural plantations [21]. This habitat diversity contributes to significant faunal and floristic richness in the region [22].

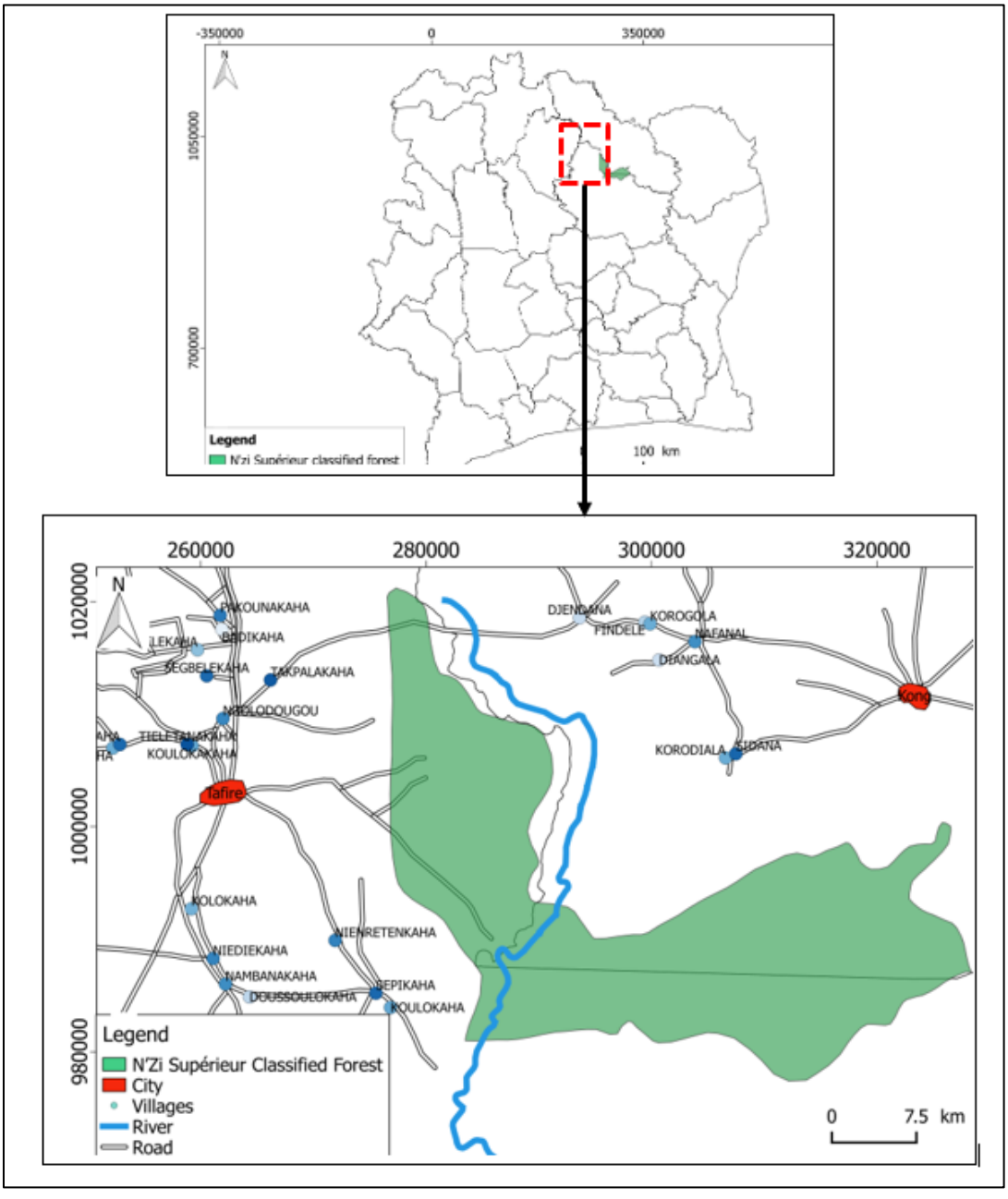

Figure 1 Location of the N'Zi Supérieur Classified Forest

2.2. Survey Technique

Data collection on elephant presence indices and anthropogenic activities in the NSCF was carried out in March 2025. It combined the linear transect method [23, 24] and reconnaissance walks [25, 26] to ensure the most comprehensive coverage possible of the study area. A total of seven (7) straight-line transects were established across the forest to represent all major landscape units of the NSCF. Elephant presence indices (footprints, droppings, feeding traces) were recorded by researchers moving at a slow pace of 0.5–1 km/h to optimize detection. Reconnaissance walks were conducted along paths of least resistance [27], particularly when locating transect starting points and in inter-transect areas, maintaining the same observation speed. Throughout these surveys, all information relating to elephant signs and observed human activities was also recorded. Inventories were conducted exclusively during the day, between 6:00 and 17:00, a period providing optimal visibility for observation and data collection [28].

2.3. Data Analysis

Dot distribution mapping was used to spatially represent the distribution of elephants and anthropogenic activities within the NSCF. This spatial analysis was based on observation and interpretation of the point distribution on the map [29, 30]. To identify areas of high concentration, distribution range boundaries, and zones of more diffuse presence, the Inverse Distance Weighted (IDW) spatial interpolation method was applied [31–33]. All cartographic processing and analysis were performed using QGIS 3.16.11, which was used to produce the predictive distribution map of elephants and the observed distribution map of the main anthropogenic threats.

3. Results

3.1. Typology of Elephant Presence Indices in the NSCF

A total of 49 indices indicating elephant presence were recorded in the N'Zi Supérieur Classified Forest. These indices break down as follows: droppings accounted for 57% of observations, footprints 21%, feeding traces 14%, and trails 8% (Figures 2 and 3).

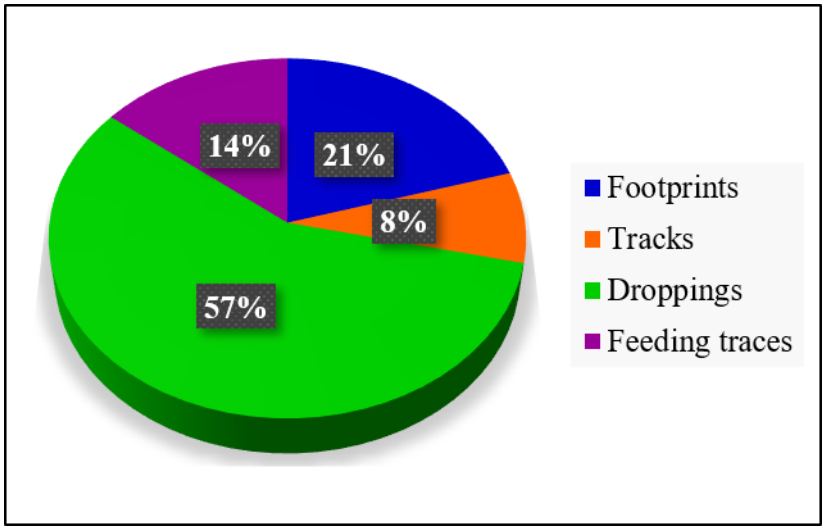

Figure 2 Types of elephant presence indices in the NSCF

Elephant dung Elephant footprint

Figure 3 Elephant presence indices in the NSCF

3.2. Diversity of Anthropogenic Activities in the NSCF

Analysis of 91 presence indices identified seven main forms of anthropogenic activity in the NSCF. In decreasing order of importance, these are: agriculture (44), transhumance (19), land clearing (9), logging (6), campsites (5), hunting (5), and plastic pollution (3) (Figures 4 and 5).

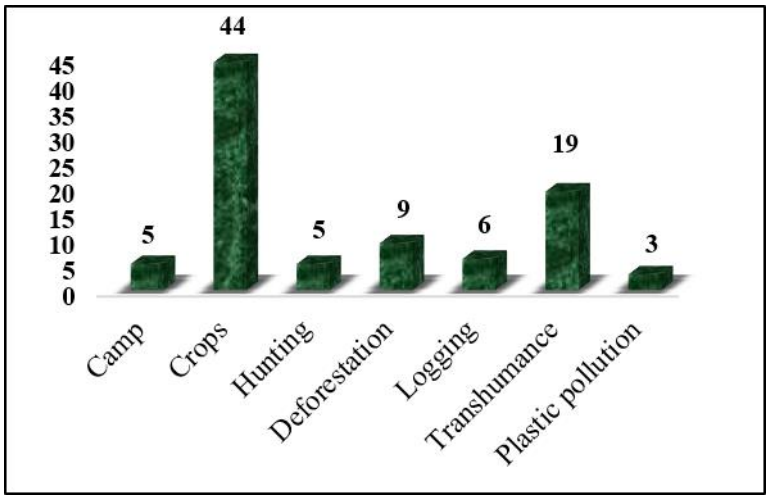

Figure 4 Types of human pressures in the NSCF

Mango plantation Transhumance

Figure 5 Anthropogenic pressures in the N'Zi Supérieur Classified Forest

3.3. Predictive Distribution of Elephants in the NSCF

Based on the recorded presence indices, a predictive distribution map of elephants was produced for the NSCF. Modeling results indicate a high probability of elephant detection in the north-eastern part of the NSCF (Figure 6).

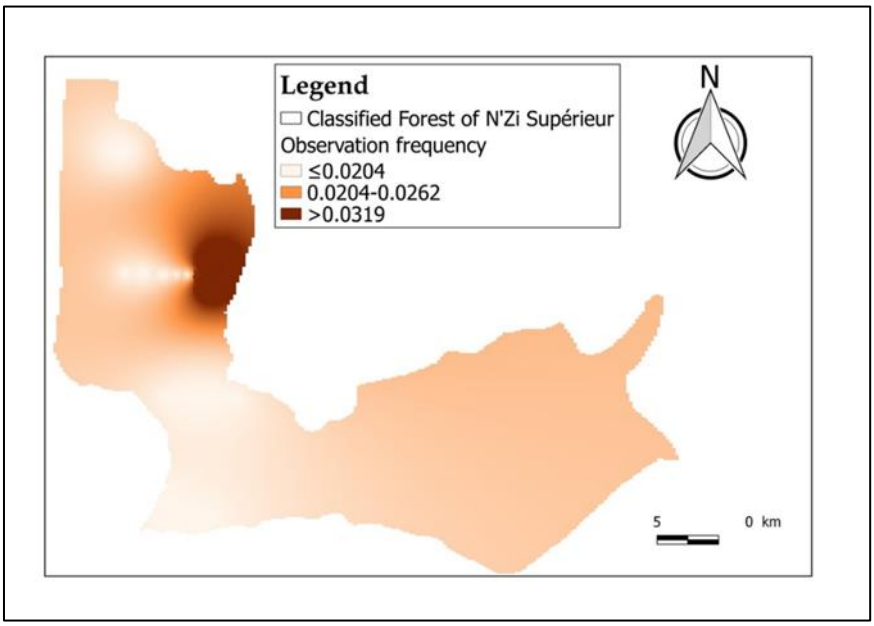

Figure 6 Predictive distribution map of elephants in the NSCF

3.4. Observed Distribution of Anthropogenic Pressures in the NSCF

The observed distribution map of anthropogenic pressures was established from presence indices collected in the NSCF (Figure 7). This map reveals a near-generalized distribution of anthropogenic activities across the entire NSCF area, with two zones of high concentration located in the centre and the north respectively. By contrast, these activities appear weak in the north-western and north-eastern parts of the NSCF.

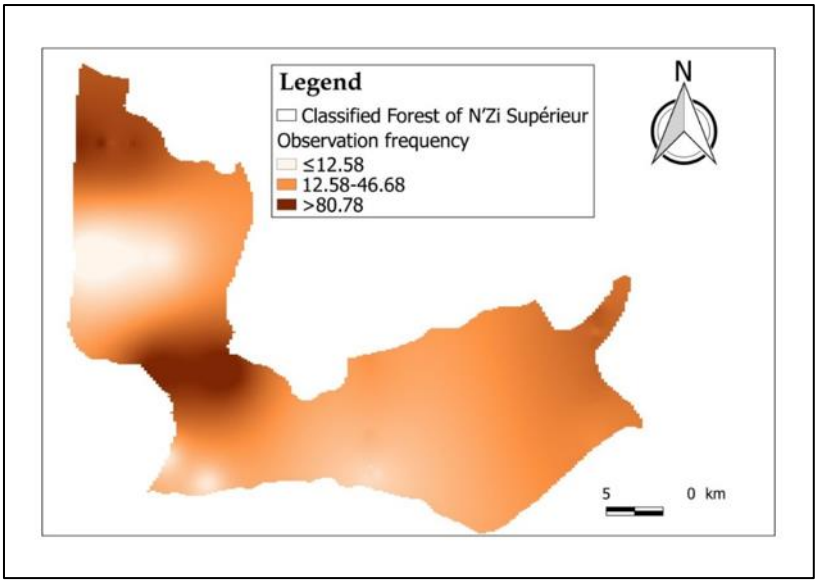

Figure 7 Observed distribution map of anthropogenic activities in the NSCF

4. Discussion

Analysis of the predictive distribution map highlights a zone of high elephant concentration within the NSCF, located in the north-eastern sector near the N'Zi River, corresponding to an open woodland area. This strong presence may be explained by the positive influence of watercourses on the spatial distribution of elephants. Similar observations have been reported by Boafo and Nandjui [34] and Kely [35] in Taï National Park, where elephant density showed a positive correlation with proximity to watercourses. The dependence of elephants on water resources has been widely documented [36–38], with several studies showing that this relationship is particularly pronounced during the dry season [37–39]. It should be noted that fieldwork in the NSCF was conducted during this period, which may reinforce this hydrological influence. Furthermore, the high concentration of elephant presence indices observed in the open woodland area may also be explained by lower levels of anthropogenic disturbance. This finding aligns with observations by Tiedoué et al. [40] and Kely [35], who showed that areas with low intensity of illegal human activities are more frequented by elephants. According to Boafo and Nandjui [34], such habitats serve as preferred refuges for the species due to reduced threats and human disturbance. The combined impacts of anthropogenic activities such as agriculture, transhumance, and land clearing may also explain the confinement of elephants to the north-eastern part of the NSCF. A similar phenomenon has been observed in other ungulates, including hippopotamuses and duikers, in Taï National Park [41–43].

The study of the observed distribution of anthropogenic pressures in the NSCF reveals near-generalized human occupation of the forest area. The map derived from presence indices shows two zones of high intensity located in the centre and north of the forest. This concentration reflects an intensification of anthropogenic pressure in these sectors, likely facilitated by easier access to the classified forests — a consequence of less stringent enforcement — and by the socio-political crisis that affected Côte d'Ivoire between 2002 and 2011 [44–46]. During this period, all protected areas beyond the control of forestry agents were subject to infiltration for exploitation, poaching, illegal artisanal mining, and other illicit activities [47–49]. Conversely, the north-western and north-eastern parts show low detectability of human activities, suggesting either lower attractiveness for anthropogenic uses or more restricted accessibility. These spatial contrasts illustrate the heterogeneous dynamics of human encroachment within the NSCF and underscore the need for differentiated management according to the level of pressure exerted on ecosystems [50].

5. Conclusion

This study has improved our understanding of the spatial distribution of elephants in the N'Zi Supérieur Classified Forest and the influence of anthropogenic activities on their presence. Results show that elephants are concentrated primarily in the north-eastern part of the forest, in connection with proximity to watercourses and areas of low human disturbance. Conversely, anthropogenic activities such as agriculture, transhumance, and land clearing are widely distributed throughout the NSCF, with hotspots of high intensity in the centre and the north. These pressures contribute to the confinement of elephants to limited refuges, potentially compromising habitat connectivity and the ecological

dynamics of the forest. These findings underscore the importance of adopting sustainable management of this forest area, combining the protection of refuge zones, regulation of human activities, and involvement of local communities. The implementation of such measures appears essential to ensure the conservation of the savanna elephant, maintain plant regeneration, and preserve the biodiversity of the NSCF in the long term.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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