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Conflict between farmers and Barbary macaques (*Macaca sylvanus*) in Northern Algeria: threats and conservation implications

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Abstract

Human-wildlife conflict is a major challenge in conservation biology with ecological and socioeconomic consequences. The problem is particularly delicate when the animals involved are threatened with extinction and experiencing rapid habitat loss due to climate change and anthropogenic actions. Here, we examined crop-foraging on farms in Central North Algeria by the Endangered Barbary macaques (*Macaca sylvanus*) to understand the conflict severity. We surveyed 94 farmers to assess the seasonal pattern, occurrence, altitudinal pattern, and consequences of crop-foraging by the Barbary macaques. We found that the Barbary macaque was widely perceived by farmers as a “nuisance”, and one third of farms were abandoned due to severe crop loss. More than 50% of farms had their crops damaged between June and September. The probability of frequent crop-foraging was driven primarily by farm-scale characteristics and landscape context: Larger cultivated area were associated with greater crop-foraging frequency, while altitude and proximity to settlements showed weaker positive associations. Our results highlight the need for sustainable solutions to enhance the coexistence between humans and Barbary macaques in the region.

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Introduction

Human-wildlife conflict has emerged as one of the most pressing challenges in ecology and biological conservation in the 21st century^{1,2,3,4,5}. Rapid and extensive land-use changes across the globe have led to the destruction of natural habitats, landscape fragmentation, and reduced ecological connectivity^{6,7,8}. These anthropogenic alterations have considerably impacted the geographic and home ranges of numerous species, particularly large mammals that require expansive territories to fulfil their vital ecological and reproductive functions^{9,10,11}. Understanding the key drivers of human-wildlife conflict affecting ecological keystone species, and other charismatic wildlife, is essential not only for mitigating its negative effects but also for implementing conservation strategies that can serve as an umbrella for protecting broader biodiversity and foster positive human-wildlife coexistence^{2,12,13}.

Over the past century, agricultural expansion has rapidly transformed ecosystems worldwide^{14,15,16}. Today, approximately 40% of the Earth's land surface is dedicated to agriculture, a figure likely to increase in response to growing human populations and rising food demands. Agricultural landscapes not only act as barriers to wildlife dispersal and contribute to environmental pollution but also frequently become foraging grounds for a variety of animals, including large mammals^{17,18,19}. This overlap in use often results in significant economic losses for farmers and exacerbates human-wildlife conflicts, which can influence the population dynamics of affected species^{19,20,21}. For species threatened with extinction, these conflicts pose particularly severe risks, especially during periods of unfavorable climatic conditions^{1,2}.

Understanding the impacts of agriculture on endangered species is therefore critical for developing effective conservation strategies that balance ecological and human needs, and encourage coexistence rather than conflict^{[22,23](#)}. Nonhuman primates, in particular, are strongly impacted by agricultural expansion throughout their ranges; the International Union for Conservation of Nature (IUCN) suggests that loss of habitat due to agriculture poses the most critical threat for 76% of primate species. In addition, model forecasts suggest that agricultural expansion over the 21st century could convert 68% of all primate habitat across the globe, overlapping with the habitat of 75% of primate species^{[24](#)}. These projections contribute to a stark picture for nonhuman primate persistence, as at least 68% of species for which adequate data are available are threatened with extinction, and 93% of primate species show populations declining^{[25](#)}.

The Barbary macaque (*Macaca sylvanus*) is native to the Atlas Mountains of Algeria, Morocco, and Tunisia. The species is currently listed as Endangered in the IUCN Red List of Threatened Species because of declines in numbers during the last decades^{[26](#)}. There is a small, introduced population in Gibraltar, which represents the only free-living nonhuman primates in Europe. While Barbary macaques inhabit a variety of environments, they are closely associated with forest ecosystems, including those in coastal regions. Barbary macaque group sizes vary with habitat type: long-term demographic studies in Algeria report smaller, more stable groups in humid oak forest (Akfadou; ~33–53 individuals) and much larger aggregations in other habitats (Tigounatine, up to ~ 88 individuals before fission events)^{[27](#)}. They are primarily herbivorous and insectivorous, and the species faces numerous threats such as drought, forest fires, poaching, and health issues like obesity associated with human feeding^{[26,28,29,30,31,32,33,34,35](#)}.

Alongside broad environmental pressures, interactions between Barbary macaques and humans have become a growing source of conflict. Agricultural expansion and pastoral practices bring them into closer contact with people, where their ecological flexibility and crop-foraging behavior create both opportunities and risks. Human presence and infrastructure influence patterns of space use and habitat selection,

shaping when and where macaques interact with people and their activities³⁷. These external pressures intersect with the species' own social dynamics, as the ability to manage stress and maintain cohesion within groups plays a role in their resilience under anthropogenic disturbance³⁸. Such conflicts pose growing challenges for both conservation and local livelihoods, highlighting the need for context-specific assessments of the drivers and consequences of human–Barbary macaque interactions. Despite increasing attention to human–Barbary macaque interactions in Morocco, there remains a notable lack of studies documenting such conflicts in North Africa, particularly in Algeria. This geographic gap limits our understanding of how conflict unfolds across the species' range and constrains the development of evidence-based conservation strategies adapted to local contexts.

In this study, we investigate farmer–macaque conflict in Bejaia Province, central North Algeria. Our objectives were to (1) characterize farmers' perceptions and experiences of Barbary macaque conflict, (2) identify the main crops targeted and the nature of the reported damage, (3) document the mitigation measures used against macaques, and (4) analyse the ecological and farm-level drivers influencing the occurrence of crop-foraging incidents of macaques during these events.

Methods

Ethical approval

The study protocol was approved by the Local Ethics and Deontology Committee of the University of Bejaia, Algeria (Decision N°431 of 06/03/2018; Ref. 01/C.E.D/UB/2024). All methods were performed in accordance with the relevant guidelines and regulations. All procedures complied with European Union directives regarding the protection of animals used for scientific purposes (Directives 86/609/EEC, 2003/65/EC, 2010/63/EU, and 2020/569/EU). Prior to data collection, we obtained necessary permits from both the National Park of Gouraya and Forest Conservation authorities. The study involved a questionnaire survey with farmers to assess human conflict and coexistence with Barbary macaques. All participants were informed about the study objectives and provided voluntary informed consent before

participation. Data were anonymized during collection and analysis to ensure participant confidentiality.

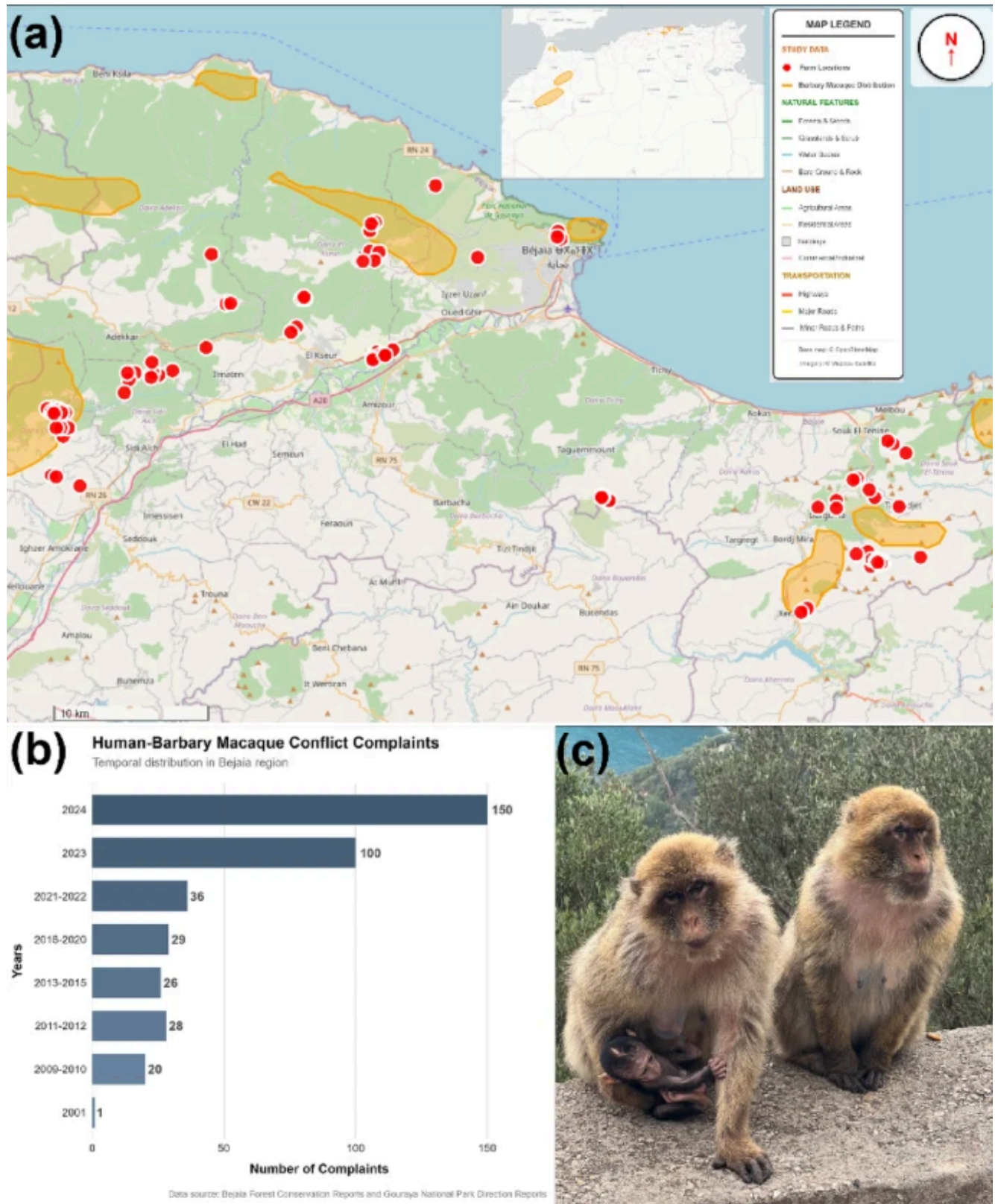
Study area

The study was conducted in Bejaia Province, located in the northeastern part of Algeria (36°43'N, 5°04'E), approximately 220 km east of Algiers (Fig. [1a](#)). Spanning an area of 3,268 km² and comprising 52 communes (small units of local government, i.e., the equivalent of municipalities), the province spans near sea level up to high peaks in the Kabylia massifs (within the provincial boundaries, the highest elevations are roughly 1,600–1,700 m). Approximately three-quarters of the province is mountainous, such that altitude is tightly linked to habitat type (forest extent and composition), human land use (agricultural intensity and settlement patterns), and access routes. The region exhibits a typical Mediterranean climate, characterized by mild, humid winters and hot, dry summers. The annual precipitation cycle is marked by a rainy season from October to May and a dry season from June to September. Recent climate studies have highlighted important climatic shifts in the region, including reduced precipitation and increased temperatures, which pose substantial challenges to local biodiversity and agricultural sustainability³⁹. Forest cover in Bejaia Province has declined substantially over the past two decades. Based on Landsat satellite imagery⁴⁰, annual forest loss has accelerated in recent years, with a peak loss of 16,566 ha recorded in 2023 alone (Fig. [2a](#)). Cumulatively, the province lost approximately 50,400 ha of forest between 2001 and 2023, representing a 40% reduction from baseline forest cover (Fig. [2b](#)). Meanwhile, agricultural land use statistics for the province show no change in total agricultural area between 2014 and 2021 (Table [S1](#)).

Agriculture plays a crucial economic role in Bejaia Province, with a total agricultural land area of 130,348 ha (productive area) dedicated to diverse crop production, including fruits, cereals, and legumes. The region, particularly its mountainous areas, is predominantly rural, with farming systems managed by smallholder farmers who rely on traditional cultivation methods for subsistence. Olive and fig cultivation are especially prominent, well adapted to the steep terrain and local conditions. However, these mountain farming communities face increasing challenges, notably rising

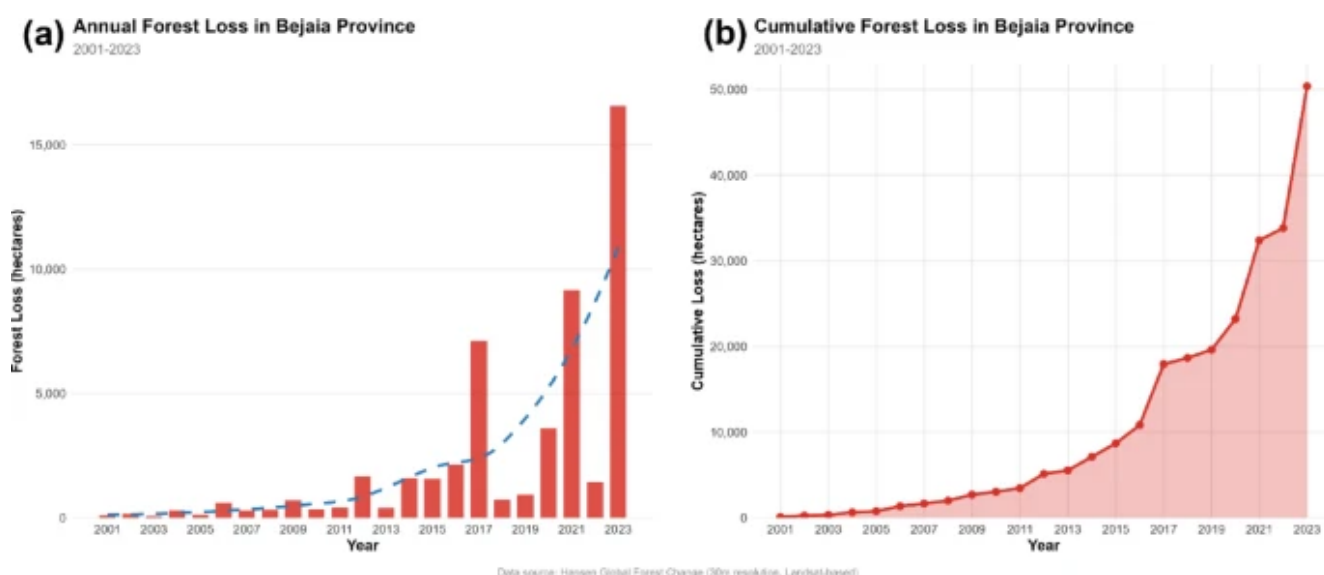
macaque incursions into agricultural areas that threaten both their agricultural productivity and food security³⁹(Fig. 1b). Although wild boar (*Sus scrofa*) and crested porcupine (*Hystrix cristata*) also cause occasional crop damage in the region, it is the Barbary macaque (Fig. 1c) that remains the primary driver of human-wildlife conflict.

Fig. 1



Geographic distribution of the Barbary macaque and human-macaque conflict study in Northern Algeria. **(a)** IUCN-defined geographic range of the Barbary macaque (orange polygons) overlaid on a land use/land cover (LULC) map of the study area. The red box indicates the location of Bejaia province. Red dots mark farms experiencing macaque crop-foraging incidents that were included in this study. The map was generated by the authors in R version 4.5.2 (<https://www.r-project.org/>)⁴¹ using the packages sf version 1.0–23 (<https://CRAN.R-project.org/package=sf>)⁴², osmdata version 0.3.0 (<https://CRAN.R-project.org/package=osmdata>)⁴³ and leaflet version 2.2.3 (<https://CRAN.R-project.org/package=leaflet>)⁴⁴. Base geography and land use/land cover data were obtained from OpenStreetMap contributors via osmdata, available under the Open Database License (<https://www.openstreetmap.org/copyright>). **(b)** Temporal trends of human-macaque conflict reports from 2001 to 2024 recorded by GNP and Forest conservation authorities (GNP and Forest conservation unpublished data). The increase in the number of reports could be due to an increase in the awareness of the public about the human-Barbary macaque conflict in the region. **(c)** Adult female Barbary macaques (*Macaca sylvanus*) with an infant, Bejaia region, northern Algeria.

Fig. 2



Estimated forest cover loss in Bejaia Province (2001–2023) derived from Hansen et al.⁴⁰ (Global Forest Change, <https://glad.earthengine.app/view/global-forest-change>). **(a)** Estimated annual forest loss showing increasing trends, with peak loss of 16,566 ha in 2023. Dashed line shows LOESS smoothed trend. **(b)** Estimated cumulative forest loss reached 50,386 ha by 2023, representing about 40% of baseline estimated forest cover (2000).

Data collection

Sampling design

We employed a random sampling approach to investigate conflict between farmers and macaques across Bejaia Province. Our sampling frame encompassed 21 communes (i.e., smallest administrative territorial unit in Algeria) with confirmed macaque populations, of which 11 had officially reported conflicts to local authorities. However, our field investigations revealed that human-macaque conflicts occurred across all communes with macaque presence, regardless of official reporting status, indicating that many farmers do not lodge formal complaints despite experiencing crop-foraging by macaques. We conducted our study across 12 communes, with crop-foraging by macaques, later categorized based on their frequency: regular (daily occurrences during the conflict period) versus occasional (three or fewer incidents monthly). The selection of farmers was conducted through collaboration with Forest Conservation and Gouraya National Park specialists, who provided access to lists of farmers in the selected communes whose lands were located within known macaque habitats or in surrounding agricultural areas. Farmers were selected to represent a range of spatial relationships to macaque forest habitats, from farms located directly within forested areas to those in nearby agricultural zones. From these lists, participants were randomly selected, resulting in a final sample of 94 farmers across the 12 communes. For each farm, we recorded the farming status: actively managed (i.e., under cultivation and management by farmers) and abandoned farms (i.e., reported by farmers as uncultivated/unmanaged for at least one year due to macaque incursions).

Farmer interviews

Semi-structured interviews were conducted between January 15th, 2024, and November 20th, 2024. Such interviews are a widely used approach in conservation research, as they allow for both structured, quantitative data with consistency across interviews, and the ability to adapt questioning based on participants' expertise and experiences⁴⁵. The English version of the survey questionnaire is provided in the Supplementary Materials. Interviews were carried out in participants' preferred languages (Tamazight, Arabic, and French), with each interview lasting between 30 and

45 min. Given the sensitive nature of discussions and legal protection for the species, interviews were not audio-recorded. Instead, we meticulously documented participant responses through detailed handwritten field notes, capturing nuanced insights into human-wildlife interactions. The comprehensive interview protocol examined multiple ecological and social dimensions of human-wildlife conflict, including farm characteristics (size —taken from official land-registry documents when available, otherwise from the farmer's own estimate for fragmented or unregistered plots—, crop types, farming experience assessed as number of years of farming activity), farmers' prior wildlife conservation training, detailed accounts of macaque crop-foraging activities — including the estimated number of groups and their sizes as reported by farmers—, temporal foraging patterns (distinguishing between dawn, midday, and dusk), crop consumption and damage assessments (Fig. [S1](#)), farmers' monitoring and mitigation strategies.

Crop damage assessment

For each farm and crop, crop physical damage was assessed qualitatively through a combination of direct field observations ($n = 79$ farms [84%]) and farmers' self-reports ($n = 15$ farms [16%]). We specifically recorded the following visible damage indicators: partially or fully consumed fruits, broken branches, bark stripping, trampled crops, and uprooted plants. These self-reported figures were cross-verified through a single on-site assessment where we also looked for direct signs linking damage to Barbary macaques, including sightings, faeces, tracks, and characteristic feeding marks. Additionally, farmer-supplied photographs taken between visits were used only as supplemental evidence and were explicitly compared with on-site findings. This ensured accurate attribution of the macaque as the source of damage. Summary patterns of crop-specific damage assessment are provided in Supplementary Table S2.

To mitigate potential reporting biases and enhance data reliability, we implemented a triangulation approach, a key methodological strategy in conservation social science to ensure robustness and validity of qualitative research findings⁴⁶. This involved cross-verifying farmer interviews with independent expert assessments from Forest Conservation and Gouraya National Park specialists, conducting systematic on-site

field observations of impacted agricultural areas, comprehensively documenting physical crop damage evidence, and meticulously recording the diverse range of farmer-implemented deterrent methods.

Spatial data preparation

Farm locations were obtained through handheld GPS surveys, with coordinates recorded in degrees–minutes–seconds (DMS) format and later converted to decimal degrees for consistent geographic referencing in the WGS84 coordinate system (EPSG:4326). Forest habitat data were sourced from OpenStreetMap (OSM), where polygons tagged as “forest” or “natural wood” were compiled within a 30–50 km buffer surrounding all farms to capture the broader landscape context. For each farm we identified the nearest forest patch using Euclidean distance in projected UTM Zone 31 N coordinates (EPSG:32631) to ensure metric accuracy. All spatial data from OpenStreetMap (OSM) were visually verified against satellite imagery, and geometries were validated with *st_make_valid* before calculations.

To characterise human influence on macaque movements, we also derived two additional spatial descriptors: (i) barrier density, the density of natural and anthropogenic features such as roads, rivers, buildings and settlements within a 1 km buffer around each farm, and (ii) distance to the closest human settlement, measured as the minimum Euclidean distance from each farm to a settlement centroid. Together, these variables provided a landscape-scale description of forest availability and potential physical or anthropogenic constraints on macaque crop-foraging.

Forest patch size and distance to forest

Forest polygons were retrieved from OSM (tags `landuse = forest` and `natural = wood`) and merged. We defined forest patches as contiguous forest areas ≥ 130 ha. This threshold represents a conservative estimate between reported values for crop-foraging groups (26 ha home ranges⁴⁷ and the 300 ha minimum required to sustain groups in purely fragmented forest habitats⁴⁸, accounting for the suboptimal habitats and resource supplementation typical of farm-adjacent landscapes in our study area. Patch areas were computed using *st_area*. The minimum Euclidean distance from each

farm to the nearest forest patch was calculated using *st_distance* between farm points and forest boundaries (*st_boundary*), extracting the minimum with *which.min*.

Landscape barriers

To quantify structural constraints on macaque movements, we created 1 km buffers around each farm using *st_buffer*. Potential barriers were retrieved from OSM and categorized as: (1) Linear features—major roads (motorway, trunk, primary, secondary), minor roads (tertiary, residential, service, track), pedestrian paths (footway, cycleway), physical barriers (fence, wall, hedge), waterways (river, stream, canal), and railways—, and (2) areal features—buildings and settlements (landuse = residential/commercial/industrial), amenities (parking, school, hospital), waterbodies (natural=water, landuse = reservoir), natural barriers (wetland, scrub, cliff), and modified agriculture (orchard, vineyard). All features were intersected with buffers using *st_intersection*. Linear barrier density (km km^{-2}) was calculated from *st_length* divided by buffer area. Areal coverage was calculated as percentage cover of the buffer zone (1 km^2) using *st_area*. To avoid double-counting overlapping features (e.g., buildings within residential zones), built environment components were merged using *st_union* before calculating total built coverage.

Distance to settlements

The minimum Euclidean distance from each farm to the nearest human settlement was calculated within a 20 km search buffer. Settlement data were obtained from OSM features tagged as landuse = residential/commercial/industrial/retail (polygon features) or place = village/town/city/hamlet/suburb (point features). All distances were calculated to settlement centroids using *st_centroid*: for polygon-based settlements, centroids represent the geometric center of the settlement area; for point-based settlements, distances were calculated directly to the point location.

Statistical analysis

All statistical analyses were conducted in R 4.5.2^{[41](#)}, and spatial analyses were performed using the *sf*, *osmdata* and *leaflet* packages^{[42,43,44](#)}. Summary statistics were generated using the *gtsummary* package^{[49](#)}. Continuous farm and landscape variables were compared between active and abandoned farms, and between farms

experiencing daily versus occasional crop-foraging, using Wilcoxon rank-sum tests (Mann–Whitney U). Effect sizes are reported as rank-biserial correlations (r). We used a generalized linear mixed modelling framework to assess whether frequent crop-foraging by Barbary macaques at the farm level (binary response variable; 1 = daily, 0 = occasional) was associated with altitude, farm area, number of crops, barrier density, distance from forest, and distance from human settlement (explanatory variables). Models were fitted with a binomial error distribution and a logit link function using the `fitme` function in the `spaMM` package⁵⁰, incorporating a spatial autocorrelation structure based on farm coordinates to account for spatial dependence among observations. An observation-level random effect (OLRE) was included to absorb residual overdispersion not captured by the fixed effects or the spatial term. All predictors were checked for collinearity using variance inflation factors (all $VIF < 3$) and were standardised (z-transformed) to facilitate comparison of effect sizes on a common scale. In a preliminary screening step, each predictor was evaluated individually within the full spatial model framework; variables whose individual contribution was negligible ($P > 0.20$)—namely distance to forest, number of crops, and barrier density—were excluded from subsequent modelling to avoid overfitting. The final model retained three fixed effects: cultivated area, altitude, and distance to the nearest human settlement. Model assumptions were verified using simulation-based scaled residuals implemented in the `DHARMa` package⁵¹. Values are mean $\pm$ SD.

Results

Farmer sample

Table 1 summarizes the demographic and farming characteristics of the 94 farmers interviewed in this study, along with their experiences and perceptions regarding Barbary macaque conflicts. The interviewed farmers were located across 12 communes. The average age was 57 ± 11.6 (range: 26–82) years, the average cultivated area was 3.1 ± 3.2 (range: 0.5–20) ha, and the average number of crops grown was 10.1 ± 5.6 (range: 1–23) crops. All farmers were males with an average farming experience of 27.8 ± 16.6 (range: 0–60) years. Most of them (96.8%) attended at least primary school and 15% had a university degree. The percentage of household income

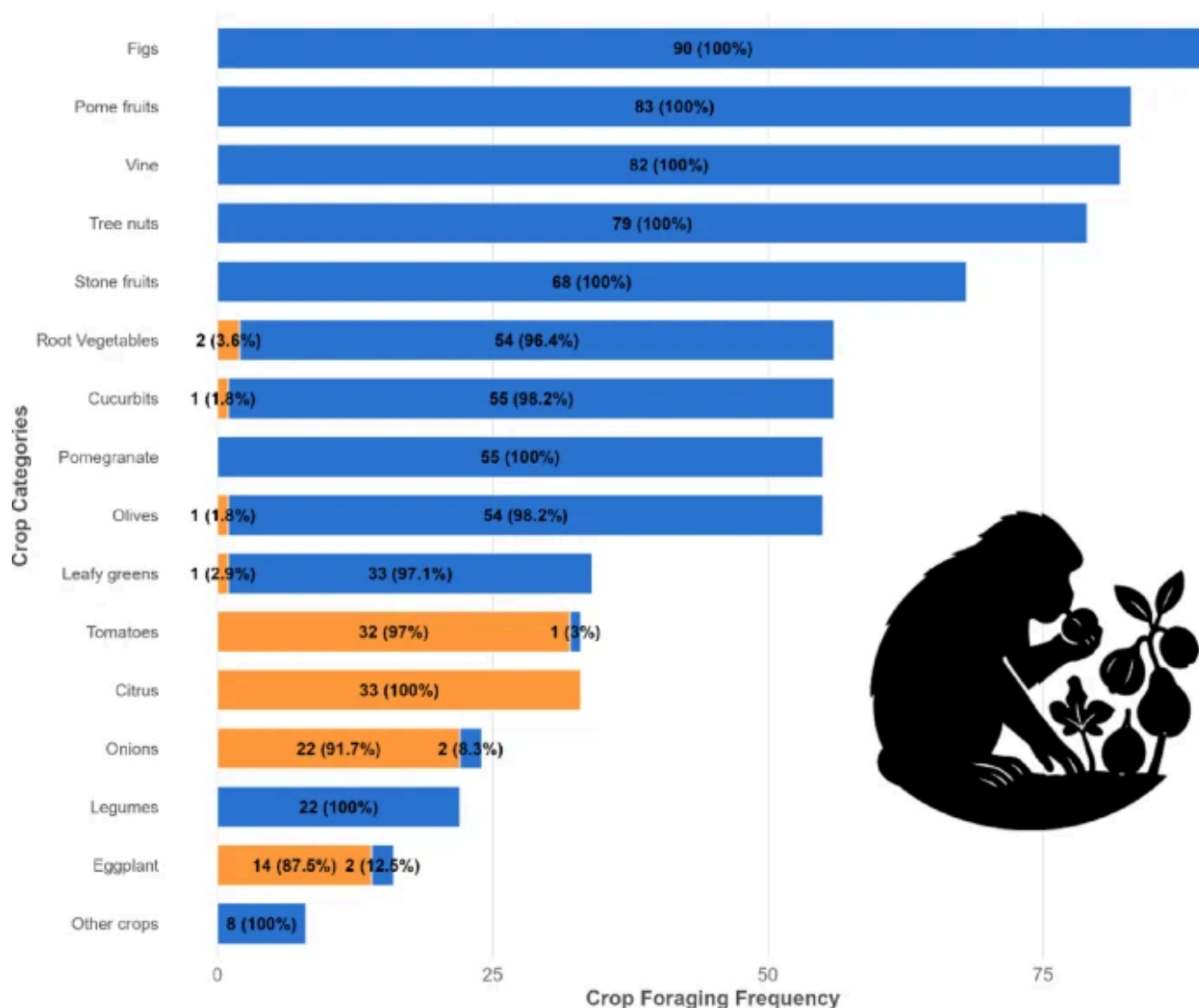
generated from farming was $34.7 \pm 24\%$ (range: 5-100). Almost all (98%) farmers had not received wildlife training. The altitude of farms varied between 18 and 944 m above sea level, showing a mean of 450 ± 281 m. All farmers reported encounters with Barbary macaques causing crop damage, and about one-third of the farms (32%) had been abandoned at the time of the survey.

Table 1 Socio-demographic characteristics, farming practices, and perceptions of farmers experiencing Barbary macaque crop-foraging in Bejaia province.

Foraged crops

Barbary macaques in Bejaia Province were reported by farmers foraging across a wide range of crop categories (Fig. 3). Among all crop categories, figs exhibited the highest foraging frequency ($n = 90$, 95.7% of surveyed farms), with full fruit consumption recorded across all instances. Pome fruits ranked second ($n = 83$, 88.3%), likewise exclusively subject to full consumption. Several other crop categories were also frequently targeted, including vine crops ($n = 82$, 87.2%), tree nuts ($n = 79$, 84.0%), and stone fruits ($n = 68$, 72.3%), all of which exhibited full consumption in every recorded foraging event. Pomegranate ($n = 55$, 58.5%) and legumes ($n = 22$, 23.4%) followed the same pattern, with no partial consumption documented. Root vegetables ($n = 56$, 59.6%) and cucurbits ($n = 56$, 59.6%) displayed comparable trends, with full consumption accounting for 96.4% and 98.2% of observations, respectively. Olives ($n = 55$, 58.5%) were similarly subject to predominantly full consumption (98.2%), with only marginal partial consumption (1.8%). Leafy greens ($n = 34$, 36.2%) followed a similar trend, with full consumption recorded in 97.1% of instances. In contrast, several crop categories were characterised by predominantly partial consumption—potentially reflecting taste aversion, reduced palatability, or exploratory foraging behavior. Most notably, citrus fruits ($n = 33$, 35.1%) were partially consumed in all documented instances. Tomatoes ($n = 33$, 35.1%), onions ($n = 24$, 25.5%), and eggplants ($n = 16$, 17.0%) were also predominantly subject to partial consumption, with respective rates of 97.0%, 91.7%, and 87.5%. These patterns may indicate selective foraging strategies or learned avoidance of certain crop types by macaques.

Fig. 3



Proportion of macaque foraging events by crop category in agricultural settings of Bejaia Province. Horizontal bars show the number of recorded macaque foraging events disclosed by farmers for each crop category. Full consumption (blue) indicates events where macaques ingested entire fruits—representing high-severity damage and direct yield loss—whereas partial consumption (orange) indicates superficial bites or fruits abandoned after initial tasting, reflecting lower-severity damage. The “other crops” category includes cardoon and prickly pear.

Mitigation barriers

Farmers disclosed the use of a diverse range of strategies to mitigate crop-foraging by Barbary macaques (Fig. S2). Active human intervention — including guarding ($n = 40$), slingshot use ($n = 26$), and dogs ($n = 32$) — was the most frequently reported approach, accounting for 62.4% of all reported mitigation measures. Physical barriers,

primarily traditional agricultural fencing ($n = 30$), represented 20.4% of measures, though electric fencing remained rare ($n = 2$). Deterrent devices, such as firecrackers ($n = 12$), sound emitters ($n = 4$), scarecrows ($n = 2$), and blank/warning shots ($n = 2$), collectively accounted for 15.3% of reported measures. Lethal methods, including poisoned baits ($n = 2$) and gunshots ($n = 1$), were rarely reported (1.9%), though this figure may underestimate actual use given the illegal or controversial nature of these practices.

Human-macaque conflict

Farmer perceptions and crop-foraging impacts

About a third (32%) of the farms were abandoned due to crop loss associated with the Barbary macaque. Farmers reported that conflicts began between 1990 and 2021 (average 2013 ± 7). On average, Barbary macaques were mainly perceived as a pest species (82%), rarely as an ecotourism resource (4%) and occasionally as both pest and ecotourism resource (13%) (1% did not respond). All farmers reported that they noticed an increase in the frequency of encounters with Barbary macaques during the last few years. Of all farms, 68% experienced daily crop-foraging by Barbary macaques. In addition to crop-foraging, a substantial proportion of farmers ($n = 53$; 56.4%) reported consequential infrastructure damage (e.g., roofing materials and drip irrigation networks) attributed to Barbary macaques, thus extending the economic impact considerably beyond direct crop yield losses. Notably, no farmers reported physical aggression from macaques or disease transmission concerns.

Spatiotemporal characteristics of farmer-Barbary macaque conflict

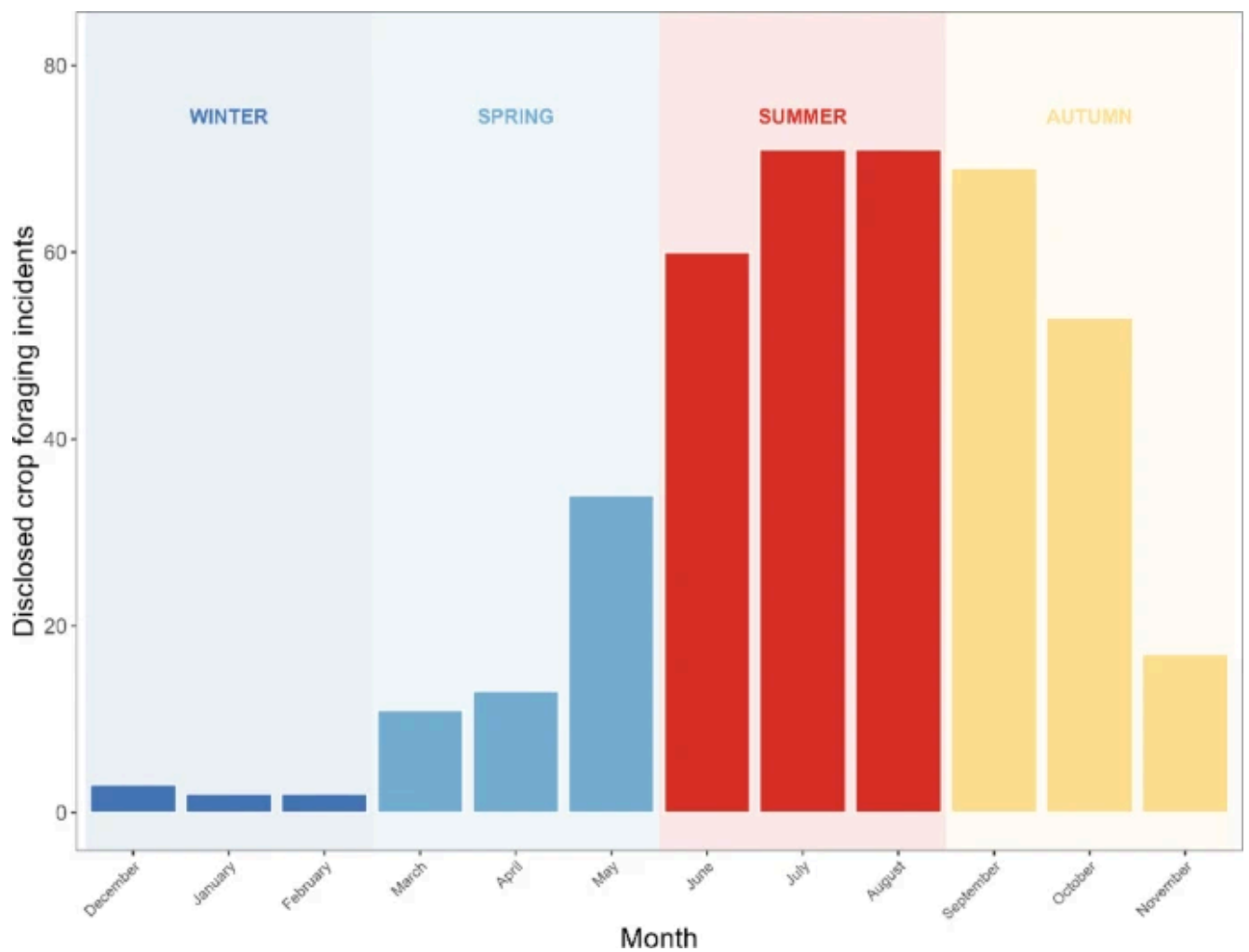
The highest frequencies of macaque encounters reported by farmers were in summer and autumn and the lowest frequencies in the winter (Fig. 4). The timing of crop-foraging varied across farms, with the most common time being dawn (87.1%), then dusk (50.5%), and mid-day (27.9%). A median of 2 [2, 3] groups (range = 1–4) were reported foraging simultaneously on farms, and the estimated median group size reported by farmers was 30 [20, 40] individuals.

Farm, landscape, and conflict-related variables differed significantly between crop-foraging frequencies and management statuses (Fig. 5, Table S3). Farms experiencing

daily crop-foraging had larger cultivated areas (3.68 ± 3.72 ha vs. 1.88 ± 1.16 ha; $P = 0.003$, $r = 0.31$), were situated closer to settlements (0.71 ± 0.75 km vs. 1.03 ± 0.62 km; $P = 0.002$, $r = 0.32$), and had higher barrier density ($P < 0.001$, $r = 0.36$) than farms with occasional crop-foraging. Farms with daily crop-foraging also had larger estimated group sizes (35 [23, 40] vs. 30 [10, 30]; $P = 0.001$, $r = 0.33$) and macaque groups per farm (2 [2, 3] vs. 2 [1, 2]; $P < 0.001$, $r = 0.38$). Distance to forest, altitude, number of crops, and number of mitigation methods did not differ significantly between the two groups.

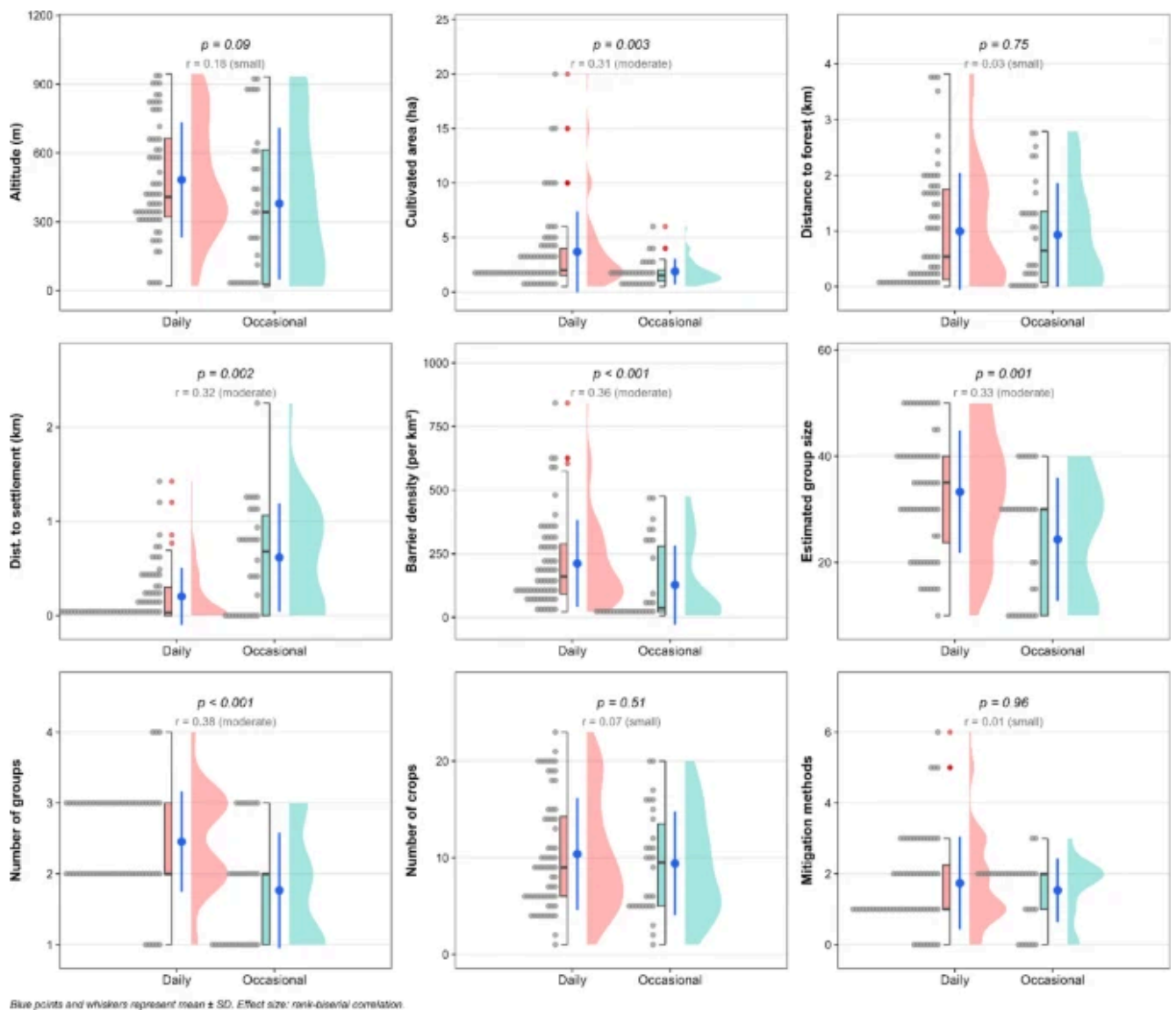
Actively managed farms ($n = 64$) were located at significantly lower altitudes than abandoned farms ($n = 30$; 334 ± 219 m vs. 697 ± 238 m; $P < 0.001$, $r = 0.56$) and closer to forests ($P < 0.001$, $r = 0.39$). Actively managed farms also supported more crop types ($P = 0.004$, $r = 0.30$) and employed more mitigation methods ($P = 0.008$, $r = 0.27$), while no significant differences were found for distance to settlement, cultivated area, barrier density, or estimated group size.

Fig. 4



Seasonal pattern of crop-foraging of the Barbary macaque on farms located in north-central Algeria.

Fig. 5



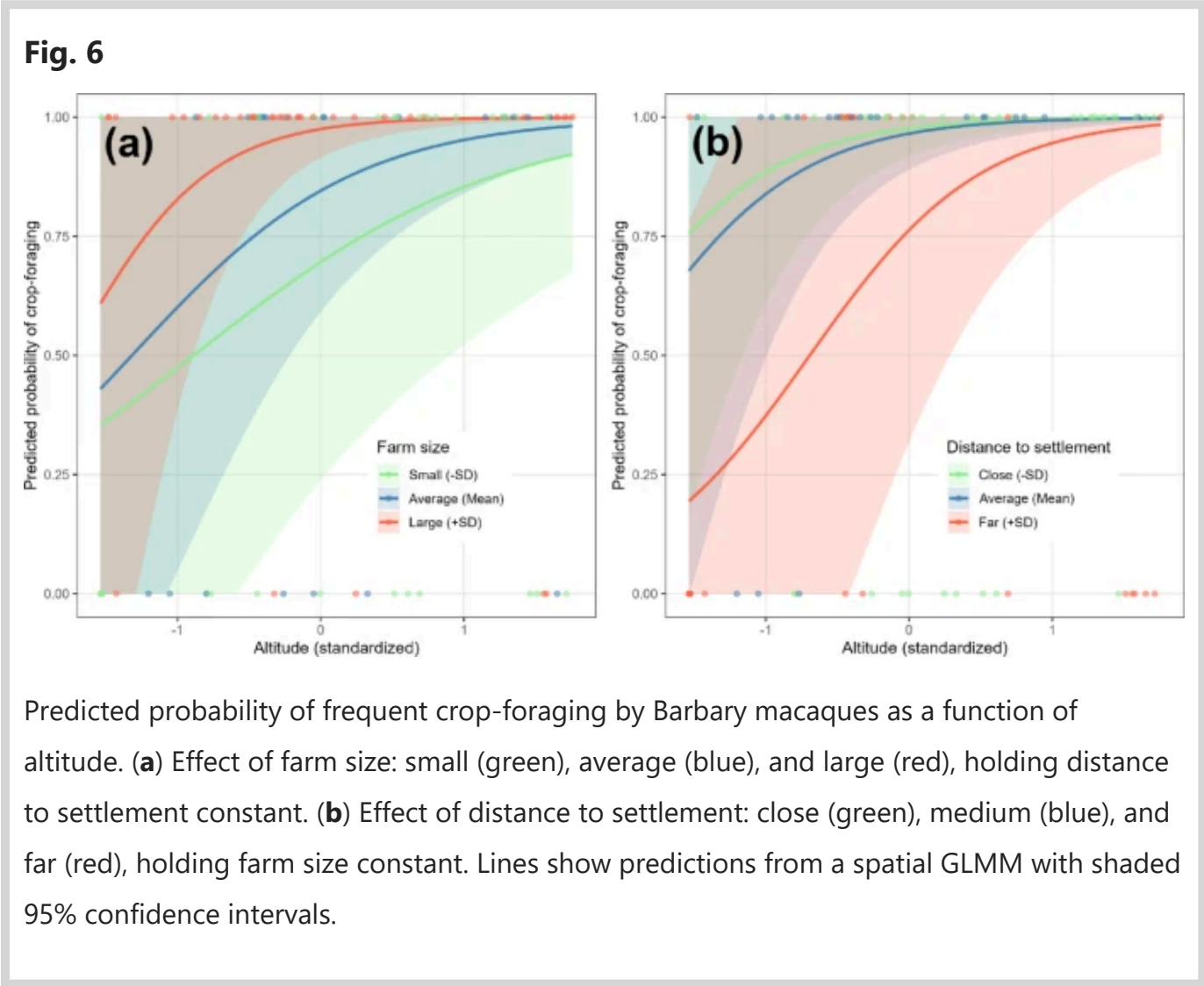
Comparison of farm, landscape, and conflict-related variables between daily and occasional crop-foraging frequencies. Raincloud plots display individual data points, boxplots (median and interquartile range), and density distributions. Blue points and whiskers represent mean $\pm$ SD. Red points indicate outliers. P-values are from Wilcoxon rank-sum tests; effect sizes are rank-biserial correlations (r).

Farm and landscape predictors of frequent crop-foraging

Crop-foraging incidents were strongly influenced by farm characteristics and landscape context (Table 2). Cultivated area was positively associated with the probability of frequent crop-foraging (adjusted OR = 12.7, 95% CI: 1.20–134, $P = 0.038$), with larger farms experiencing markedly higher odds of frequent macaque crop-foraging (Fig. 6a). Altitude showed a marginally significant positive effect (adjusted OR = 3.10, 95% CI: 0.87–11.1, $P = 0.085$), suggesting increased probability of frequent crop-foraging risk at higher elevations. Similarly, distance to the closest

human settlement had a marginally significant negative effect (adjusted OR = 0.29, 95% CI: 0.07–1.12, $P = 0.076$), indicating that more isolated farms tended to experience a lower probability of frequent crop-foraging (Fig. 6b).

Table 2 Results of the spatial generalised linear mixed model output examining the probability of frequent crop-foraging by Barbary macaques across Bejaia Province ($n = 94$).



Discussion

We examined the conflict between Barbary macaques and smallholder farmers in Central North Algeria to improve our understanding of negative interactions and inform conservation strategies for this Endangered species. Farmers consistently perceived macaques as major pests, with frequent crop-foraging contributing to the

abandonment of nearly one-third of surveyed farms. These incidents occurred most often at dawn and dusk, reflecting macaques' tendency to forage when human activity is low. Our analyses revealed that crop-foraging risk was associated with farm characteristics and landscape context.

This study reports locations of the Barbary macaque that are outside the existing occurrence data of the IUCN Red List⁵², expanding our understanding of the geographic distribution of the species in rural regions of central North Algeria. A more detailed understanding of the distribution of Barbary macaques is essential, as this species is currently restricted to small relict patches of forest and scrub-forest across its range^{53,54,55,56}.

The surveyed farms were primarily smallholder mixed-crop farms managed by single households for subsistence. On average, crops provide about 35% of total household income. Because such a large share of income depends on crops, even moderate wildlife damage can represent a substantial economic burden. This figure is higher than some studies on other macaque species (4.2% of income loss in rural Nepal by the Rhesus macaques (*Macaca mulatta*)), but slightly lower than others (41.1–58% in Buton macaque (*Macaca ochreata brunnescens*) in Sulawesi)^{57,58}. All farmers reported encounters with Barbary macaques, which caused varying degrees of damage, leading to the abandonment of one-third of the farms. These losses disrupted traditional livelihoods, forcing many farmers to rely more heavily on purchasing food from the nearest town. Such shifts in social habits of rural populations due to wildlife have been recorded in the Kakum Conservation Area, Ghana, where frequent encounters with elephants not only resulted in substantial crop losses but also forced farmers to abandon their lands, leading to increased reliance on purchased food⁵⁹. Similar to the impact of Barbary macaques in our study, this disruption alters traditional livelihoods and contributes to economic hardship, food insecurity, and social stress in affected communities⁵⁹. Unfortunately, no fully implemented national programs currently exist to support farmers facing severe conflicts with the Barbary macaque, leaving them with few options beyond enduring ongoing crop losses or abandoning their farms altogether. The Strategy and Action Plan for the Conservation of Barbary Macaques in

Algeria 2018–2027³¹ recommends the establishment of a compensation program with control mechanisms to prevent fraudulent claims and ensure fair distribution of funds to reimburse farmers for losses caused by macaques, aiming to reduce hostility and prevent retaliatory killings of these Endangered animals. However, in our study area, none of these recommendations have been implemented. Notably, almost all farmers had received no wildlife management training, highlighting a critical gap in mitigating this conflict and improving potential for coexistence.

All farmers observed an increase in macaque presence on their farms in recent years, likely driven by the scarcity of food resources in the macaques' habitat. Indeed, the forest ecosystems that the macaques inhabit are severely affected by recurrent wildfires⁶⁰. Fire incidence is particularly high in oak forests and shrublands, ecosystems that likely provide important food resources for macaques. Consistent with these dynamics, satellite-derived estimates of tree cover change indicate that Bejaia Province lost approximately 50,400 ha of tree cover between 2001 and 2023 — a 40% reduction from the 2000 baseline — with annual losses accelerating sharply and peaking at 16,566 ha in 2023⁴⁰. The temporal alignment between this accelerating deforestation and the average conflict initiation date reported by farmers (2013 ± 7) further supports the link between habitat degradation and the escalation of crop-foraging incursions. Notably, total agricultural area in Bejaia Province remained unchanged over the 2014–2021 period (Table [S1](#)), suggesting that the documented forest loss was not driven by agricultural expansion but rather by other factors, particularly recurrent wildfires that disproportionately affect oak forests and shrublands. The loss of fruit-bearing trees, shrubs, and other vegetation due to repeated fire events has likely contributed to a decline in food availability, forcing macaques to expand their foraging range into agricultural landscapes. Moreover, since vegetation recovery after fire can take years, future fire occurrences are expected to exacerbate food scarcity, leading to a sustained increase in human-macaque interactions and crop-foraging incidents. Given that fire activity in the region is largely driven by anthropogenic factors, particularly in wildland-urban interfaces, these trends suggest an escalating human-wildlife conflict scenario unless effective fire management and habitat conservation strategies are implemented⁶⁰. Previous studies

have documented similar spatial shifts and increased primate and mammal activity following habitat degradation caused by fire^{1,61}, deforestation^{62,63}, climate change¹, or natural disasters⁶⁴. Mishra et al.⁶⁴ found an increase in the frequency of conflict with the long-tailed macaques (*Macaca fascicularis*) after the Tsunami of 2004 in the Great Nicobar Island, highlighting that environmental changes can exacerbate human-wildlife conflict⁶⁴. The macaque has a broad diet and habitat preferences, which make them relatively dynamic spatially and temporally.

Our findings on the seasonal occurrence of Barbary macaque crop-foraging indicate that they are most frequently observed from late spring through autumn (May to October), with peak activity in mid-summer (from July to September) and reduced presence in late autumn and winter (November to February). This pattern is likely driven by the availability of oak acorns (*Quercus coccifera*, *Q. faginea* and *Q. afares*) in forests during the colder seasons (starting November to February), which serve as a key food source during the colder months^{35,54,65}, and suggests that given adequate wild food availability, macaques may choose wild foods over anthropogenic food sources (e.g., a similar seasonal pattern as has been documented among free-ranging provisioned Japanese macaques *Macaca fuscata*⁶⁶). Similar results were reported in Endangered blond capuchins (*Sapajus flavius*), whose foraging on sugarcane crops was inversely related to wild fruit availability⁶⁷. Similarly, Neves et al.³⁶ reported a seasonal shift in macaque crop-foraging in Aïn Leuh, Morocco, with higher presence in cultivated areas during July, August, and November and reduced crop use in May, June, and October, suggesting that macaques adjust their foraging based on food availability. Additionally, increased precipitation during autumn and winter periods frequently results in elevated river discharge, creating hydrological barriers that may further constrain dispersal patterns and movement across the landscape for these primates. The notably high foraging rate observed for figs may be another primary driving factor behind the seasonal crop-foraging patterns in the region. The observed peak in crop-foraging activity during July, August, and September directly corresponds with the maturation period of most fig cultivars in the area (Fig. S3). Ripe figs represent a high-energy, easily exploitable resource for Barbary macaques. This seasonal preference reflects the macaques' capacity for optimal foraging, highlighting

an ability to balance foraging efficiency with environmental availability⁶⁸. This creates a particularly challenging situation in Bejaia Province, which is renowned throughout the region for its high-quality fig production³⁹.

Our spatial model identified cultivated area as the strongest predictor of the probability of frequent crop-foraging, with larger farms facing substantially greater risks. This likely reflects a simple target-area effect: farms occupying a greater proportion of the local landscape present more opportunities for macaque foraging and are harder for a single household to monitor effectively. A similar relationship between farm size and crop-foraging intensity has been reported for Rhesus macaques in Nepal⁵⁷ and Japanese macaques in Japan⁶⁹. Additionally, farms situated closer to human settlements tended to experience more frequent foraging incursions. Although this effect was marginal in our model, it may reflect the concentration of fruit orchards and irrigated plots near villages, which provide a predictable, high-quality food source for macaques that have become habituated to human presence — a pattern consistent with town-foraging behavior documented in peri-urban Bejaia and Gibraltar^{32,70}. Higher-altitude farms were more likely to be abandoned by farmers than those at lower altitudes, a pattern consistent with the marginal positive effect of altitude on the probability of frequent crop-foraging observed in our spatial model. Descriptively, abandoned farms were also significantly closer to forests than actively managed ones (Table S3), suggesting that altitude and forest proximity covary in this mountainous landscape. This likely reflects the closer proximity of high-altitude farms to the macaques' roosting and foraging sites within adjacent forest ecosystems. Crop field foraging by macaques living at forest edges has been documented in Morocco^{36,47}, and similar conflicts involving fruit orchards have been recorded for Rhesus macaques in Nepal^{57,71}, Bonnet macaques (*Macaca radiata*) in India⁷², and Japanese macaques in Japan⁶⁹. Notably, neither distance to forest nor landscape barrier density showed meaningful associations with frequent crop-foraging in our analyses. The absence of a forest-distance effect is particularly striking, as proximity to forest edges is widely documented as a primary predictor of primate crop-foraging intensity in other systems^{20,36}. In our study area, this may reflect the advanced degree of habitat fragmentation — remaining forest patches are small, dispersed, and

interspersed with farmland, such that macaques likely range across the entire agricultural matrix rather than foraging only at forest edges. Under these conditions, the spatial gradient from forest to farm may no longer capture meaningful variation in exposure to macaque foraging pressure.

Our findings suggest that Barbary macaques exhibit risk-sensitive foraging behavior, preferring to forage on crops at dawn (87.1%) and dusk (50.5%) but not during mid-day (27.9%) when human activity is highest. This aligns with optimal foraging theory, where animals adjust their behavior to maximize gains while minimizing risks⁷³. A similar pattern was observed in Rhesus macaques in Guangxi, China, particularly in villages near the White-Headed Langur National Nature Reserve, and Nicobar long-tailed macaques (*Macaca fascicularis umbrosus*) on Great Nicobar Island, both of which predominantly foraged crops at dawn and dusk avoiding mid-day when farmers were most active^{64,74}. More surprisingly, wild chimpanzees in Kibale National Park have been observed crop-foraging at night, staying longer in maize fields and showing fewer signs of vigilance and anxiety during these nocturnal incursions⁷⁵. Interestingly, our results contrast with findings from Morocco, where Barbary macaques were reported foraging throughout the day, even during periods of high human activity, which led to frequent encounters and aggressive interactions with humans and dogs³⁶. In our study, no incidents of physical aggression to farmers were reported, and the avoidance of mid-day activity suggests that macaques in Bejaia may adopt a more cautious temporal strategy. These differences highlight the potential for regional variation in macaque foraging behavior, likely shaped by local farming practices, deterrence methods, and levels of human tolerance.

Farmers reported a diverse array of mitigation strategies, dominated by active human intervention, followed by physical barriers and deterrent devices. However, the number of mitigation methods employed did not differ between farms experiencing daily versus occasional crop-foraging, suggesting that the accumulation of deterrent measures, at least as currently practiced, does not translate into reduced foraging frequency. This observation is consistent with the broader literature on macaque crop-foraging, which highlights the capacity of these cognitively flexible primates to

habituate to and circumvent a wide range of deterrent strategies⁷⁶. Given the limitations of current practices, future efforts should explore integrated, community-based management combining technological innovations (e.g., motion-activated deterrents, reinforced electric fencing) with landscape-level strategies such as agroforestry buffer zones⁷⁷. While most reported approaches are non-lethal, there is growing concern about the use of lethal methods against these protected primates. The situation appears even more concerning in conflict hotspots like Toudja Commune, where informal discussions revealed farmers' willingness to resort to lethal methods if governmental authorities fail to implement effective solutions.

Study limitations

Although we implemented multiple strategies to minimize bias (triangulation with field observations, expert validation, and systematic spatial analyses), part of our dataset inevitably relies on farmer reports of macaque crop-foraging. Such perception-based data may be subject to recall errors or selective reporting. However, this approach is common in human–wildlife conflict research, particularly in regions where continuous direct monitoring is absent. We therefore interpret the results with caution, emphasizing the ecological patterns revealed rather than absolute frequencies of crop-foraging events.

Conclusion

This study documents a case of human-wildlife conflict involving the Barbary macaque and farmers in Central North Algeria. Our results highlight a worrisome conflict that led to the abandonment of a large number of farms, considerable crop damage, and change in the livelihood of farmers in the region. Farms of larger size, especially if they occurred at higher altitudes, were more likely to be crop-foraged by the Barbary macaques. The increased frequency of crop-foraging in recent years also points to habitat loss and loss of natural food sources for the Barbary macaques and aligns with the IUCN reports of population declines in this species. It is imperative to use existing knowledge to determine urgent research questions that attenuate the conflict, particularly because the region undergoes an increasing intensification of drought

which increases the frequency of forest fires that degrades the primary habitat of the species. Future studies should assess the effectiveness of strategies such as motion-activated deterrents (e.g., flashing lights, ultrasonic devices), bio-repellents, and reinforced electric fencing which may offer more effective alternatives. Furthermore, promoting agroforestry practices—such as planting buffer zones with less attractive crops—could help redirect macaques away from high-value crops. For instance, the predominantly partial consumption observed for citrus fruits, tomatoes, onions, and eggplants — possibly reflecting reduced palatability or taste aversion — suggests that such crops may serve as natural deterrents and could be incorporated into buffer-zone designs around high-value fruit orchards. Engaging local communities in coexistence-based approaches, including compensation schemes and wildlife awareness programs, may also enhance long-term conflict mitigation. A collaborative, science-based approach that integrates ecological research with community-driven solutions will be key to fostering sustainable coexistence between humans and Barbary macaques in the region.

Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Code availability

No new software, algorithm or computational tool was developed for this study. All analyses were performed in R version 4.5.2 using previously published, publicly available packages, each cited in the Methods and reference list (sf, osmdata, leaflet, gtsummary, spaMM and DHARMA). The R scripts used to process the spatial data and to fit the models are available from the corresponding author on reasonable request.

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Contributions

M.K.M. conceived and designed the study, developed the methodology, collected field data, conducted data analysis and created visualizations, and led the writing of the

original draft. A.C. contributed to methodology development, field investigation, data collection, and contributed to manuscript review and editing. R.B. provided resources, validated analysis and contributed to manuscript review and editing. S.T. and R.W. participated in manuscript review and editing. R.K. participated in study conceptualization, performed and validated the data analysis, created visualizations, supervised the project, contributed to manuscript review and editing, and led the writing of the original draft. All authors reviewed and approved the final version of the manuscript.

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Ethics declarations

Competing interests

The authors declare no competing interests.

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Supplementary Information

Below is the link to the electronic supplementary material.

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