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Master Degree in Valorization and Sustainable Development of Mountain Areas

Effects of tourism on Flight Initiation Distance in Alpine marmot *Marmota marmota*

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Abstract

Human activities, including tourism, influence wildlife behaviour, particularly escape responses to perceived threats. This study aimed to investigate the behavioural response of Alpine marmots *Marmota marmota* to human presence in the Mont Avic Natural Park (northwestern Italian Alps). By comparing flight initiation distance (FID) between two areas, one with high levels of tourist activity and a control area with restricted access, as well as evaluating the influence of daily tourist counts in the tourist area, the objective was to assess behavioural adjustments in response to human disturbance. FID was analyzed using linear modeling approaches, with FID as the response variable, tourist presence / abundance as predictors, and several covariates such as burrow distance, start distance, Julian date, marmot behavior at the time of observation, time of day, cloud coverage, wind intensity and number of conspecifics. The results revealed that FID was significantly lower in the tourist area compared to the non-tourist area, supporting the hypothesis that in areas without tourists marmots were more susceptible to disturbance, and that habituation likely occured in response to a frequent, non-threatening human activity. In contrast, daily tourist counts did not significantly influence FID, suggesting that variations in tourist pressure did not elicit measurable changes in marmot escape behaviour. In both models, starting distance and burrow distance were significantly and positively related to FID, with marmots fleeing at greater distances when starting further from the observer or from their burrow. While the presence of tourists clearly affects marmot escape behaviour, the available data do not allow to provide evidence that human activity negatively impacts their fitness or population dynamics. Although habituation may reduce energy costs by minimizing unnecessary flight, its long-term consequences, including potential stress or reduced reproductive success, remain unclear. A comprehensive understanding of these impacts requires additional data, such as physiological parameters (e.g., glucocorticoid levels) and long-term demographic data. These data are required to put forward management recommendations with respect to conservation measures such as tourist restrictions.

Contents

1. Introduction

Human activities are increasingly impacting natural ecosystems worldwide, with over 80% of terrestrial areas now influenced by human presence (Sanderson et al., 2002). These actions not only alter ecosystems on a large scale but also impact how wildlife populations interact with their habitats, influencing species distribution, population dynamics, and survival abilities under changing environmental conditions (Trombulak and Frissell, 2000; Nellemann et al., 2000). Besides consumptive uses (e.g., hunting), recreational activities like hiking, mountain biking, wildlife observation, and other nonconsumptive forms of tourism have documented effects on the behaviour of various animal species, often resulting in altered movement patterns, increased vigilance, and other behavioural changes (Taylor and Knight, 2003; Finney et al., 2005; Corradini et al., 2021). Many wildlife species modify their behaviour, often avoiding areas frequented by people, which may force them into less suitable habitats or reduce the time available for essential activities, such as parental care, foraging, resting, and mating displays (Burger, 1981; Klein et al., 1995; Gander and Ingold, 1997; Manor et al., 2005). These displacement behaviours reflect an attempt to minimize encounters with humans, but at a cost to the animals' overall fitness due to limited access to high-quality resources.

Human presence can act as a disturbance factor that wildlife perceives as a threat, prompting behaviours aimed at risk assessment and avoidance. For example, escape responses, where animals flee from perceived threats, are a primary example of behaviour altered by human disturbance (Frid and Dill, 2001). The escape response involves trade-offs, where animals weigh the costs of fleeing—such as abandoning a food source or expending energy—against the potential risk posed by the disturbance. According to the optimal escape theory (Ydenberg and Dill, 1986; Cooper Jr. and Frederick, 2007), animals are expected to initiate flight only when the risk of staying outweighs the potential benefits. This response, although protective, comes with high energy costs that can diminish an individual’s fitness, particularly when disturbances are frequent (Frid and Dill, 2001; Samia et al., 2015). In this context, when animals encounter non-lethal disturbances from humans, their responses can resemble those evoked by actual predators. Factors such as intensity, proximity, and predictability of the disturbance influence the degree of response, with heightened responses to more intense or unpredictable stimuli. This suggests that animals adapt their behaviour dynamically, with intensifying responses when they perceive an elevated threat (Tablado and Jenni, 2017; Lasky and Bombaci, 2023).

While some species avoid human-occupied areas, others adapt to the presence of humans by developing tolerance through a process called habituation (Rankin et al., 2009). Habituation is a form of behavioural plasticity in which an animal reduces its response to repeated non-threatening stimuli, essentially "learning" that the human presence does not constitute a direct threat. This adaptation allows them to conserve energy that would otherwise be spent on frequent escape responses, thereby potentially improving their fitness in human-altered environments (Mery and Burns, 2010; Blumstein, 2016). This response is commonly observed in species inhabiting urban or tourist-heavy areas where repeated exposure to humans leads to a gradual decline in vigilance and avoidance behaviours (Samia et al., 2015). Habituation, however, may mask underlying costs, particularly for species with limited mobility or those confined to specific habitats where escape options are restricted. For these species, even subtle changes in behaviour may lead to significant long-term demographic impacts, including reduced survival or reproductive success (Gill et al., 1996; Liley and Sutherland, 2007).

To quantify risk tolerance and evaluate how disturbances impact animals' behavioural adjustments over time, a commonly used metric in behavioural ecology is the Flight Initiation Distance (FID) (Cooper Jr. and Frederick, 2007). FID measures the distance at which an animal flees from an approaching threat and is commonly used to assess the degree of an animal's response to human disturbance. (Ydenberg & Dill, 1986). While in the short term, increased FID may provide information on an aversive response to a threat, repeated exposure to low-risk stimuli, such as hikers or photographers, can result in decreased FID, indicating habituation as animals learn that these interactions are unlikely to pose a direct threat (Rankin et al., 2009; Samia et al., 2015). To date, numerous studies have demonstrated that human disturbance significantly influences FID in various mammalian species, confirming that animals exposed to frequent human activity adjust their escape behaviours accordingly (Manor et al., 2005; Malo et al., 2011; Engelhardt and Weladji, 2011; Mbise et al., 2020; Meisingset et al., 2022). For instance, in a study on rock hyrax—*Procavia capensis johnstoni* and bush hyrax—*Heterohyrax brucei* in the Serengeti, repeated exposure to non-threatening human presence was shown to reduce FID substantially, as animals began to tolerate closer approaches without initiating flight. This shift in FID suggests a recalibration of perceived risk, whereby animals modify their anti-predator responses in response to predictable human disturbances (Mbise et al., 2020). Such behavioural adjustments highlight the ability of some species to modulate escape responses based on environmental cues and perceived risk levels, potentially reducing the energetic costs associated with unnecessary flight in human-dominated landscapes. While shifts in behaviour and distribution in response to human disturbance are evident, their demographic

impacts—such as effects on survival and reproduction rates—are not always straightforward to measure.

This study investigates the behavioural response of the Alpine marmot *Marmota marmota*, a species confined to alpine meadow habitats with limited dispersal capabilities, to human disturbance. By systematically comparing populations in areas with high levels of tourist activity, such as along heavily trafficked trails, to those in areas with no human presence, I aim to determine if habituation to human disturbance occurs and to identify any behavioural variations attributable to sustained anthropogenic exposure.

2. Study species

The Alpine marmot *Marmota marmota* is a large, ground-dwelling rodent, occurring in the high-altitude Alpine and subalpine meadows of the European Alps, the Pyrenees, the Carpathians and the Apennines (Zelenka, 1965) (Fig. 1).

Figure 1. Distribution of Alpine marmots in Europe according to the IUCN (Cassola, 2016) (a). Picture of an adult of Alpine marmot in the Mont Avic Natural Park (photo by Anna Foieri) (b).

Marmots are members of the Sciuridae family, which also includes squirrels and prairie dogs, and are one of the largest hibernating mammals, with adults weighing between 3 to 8 kg depending on the season (Boero, 2001). It is a social and highly cooperative species, living in family groups of 2 to 20 individuals. These family groups typically consist of a dominant breeding pair and their offspring of various ages, including juveniles born during the current year, as well as older offspring that have postponed dispersal. These non-breeding individuals do not reproduce but instead assist their parents in rearing younger siblings (Allainé, 2000). They exhibit a territorial behaviour with each family group defending territories with complex burrow systems consisting of interconnected chambers and tunnels used for protection against predators, as well as for hibernation (Blumstein et al., 2004). The average territory size for Alpine Marmots ranges from approximately 0.9 to 2.8 ha (Perrin et al., 1993). In addition to the burrow system, the territory usually includes foraging ground and open spaces for sunbathing and social interactions (Pasquaretta et al., 2015). Marmots are diurnal animals and their activity is bimodal, with peaks occurring during the early morning and late afternoon (Armitage and Salsbury, 2015). The active season for this species typically spans from April to October, during

which they actively forage to accumulate fat reserves, used to survive the winter hibernation that can last up to seven months (Zelenka, 1965; Arnold, 1990). Marmots depend heavily on a brief active season during the warmer months to accumulate the energy reserves. This constraint likely shaped the cooperative breeding structure where helpers increase the survival chances of pups by participating in thermoregulation, alloparental care, and predator vigilance (Arnold, 1990). During this short period, marmots must optimize their foraging efficiency to gather sufficient fat stores to survive the winter months; disturbances during this critical time can have consequences for their overall fitness. For example, disruptions that interfere with their ability to forage effectively or that increase their energy expenditure through heightened levels of vigilance may reduce the energy they can allocate to essential tasks, such as fat accumulation and reproduction. (Li et al., 2011; Ruf, 2023).

This challenge is exacerbated by rising levels of anthropogenic disturbance from outdoor recreational activities, which peak during the summer months when marmots are actively foraging. In recent decades, tourism in the Alpine region has increased substantially, particularly in areas that were previously less accessible. This seasonal peak of human activity coincides with the marmots' critical period for resource accumulation, leading to increased potential disturbance exposure. According to the European Environment Agency (EEA), tourism in the Alps has risen by over 40% since the 1990s, driven by developments such as ski resorts and popular activities like hiking and mountain biking (European Environment Agency, 2018). The overlap between peak human presence and the marmots' essential preparatory period for winter could thus compromise individual fitness, with implications for population stability and resilience.

Several studies have examined the impacts of tourism and other human activities on marmot species. These studies highlight the influence of human disturbance on marmot behavior, including changes in foraging efficiency, vigilance levels, and habituation (Neuhaus et al., 1989; Mainini et al., 1993; Griffin et al., 2007; Li et al., 2011). Research indicates that marmots exposed to consistent human presence may develop reduced FID, reflecting a learned tolerance to non-threatening human activities (Uchida et al., 2022; Morgan et al., 2021). The ability of marmots to exhibit varying degrees of FID based on the type and intensity of human disturbance allows to explore the relationship between environmental factors and behavioral responses.

3. Objectives

The primary objective of this study was to assess the influence of tourist presence on the flight initiation distance (FID) of Alpine marmots, as a behavioral measure of their response to perceived threats. By comparing FID in two distinct areas within Mont Avic Natural Park—one with high levels of tourist activity and a control area with restricted human access—this study aims to quantify the effects of anthropogenic disturbances on marmot behavior. This comparison will provide insights into how repeated exposure to human presence may alter marmots' adaptive risk responses in natural habitats.

Based on existing literature examining the effects of human disturbance on wildlife behavior, I hypothesized that differing levels of anthropogenic activity will lead to measurable variations in the FID of Alpine marmots. Research has shown that animals frequently exposed to non-threatening human presence adjust their risk assessment, often resulting in a reduced FID due to habituation processes. This reduction in FID is often a result of repeated encounters where human presence does not correlate with negative outcomes, prompting animals to conserve energy by fleeing at shorter distances. Therefore, I predicted that marmots in an area with regular tourist presence during the summer season, would show lower FID than those in the tourist-free control area, where access is limited. Furthermore, a correlation between increased human disturbance and reduced FID has been documented, particularly during peak tourist seasons, indicating that animals adjust their flight response based on human presence density. Based on this evidence, I expected marmot FID to decrease as tourist activity intensifies and to eventually stabilize over the course of the season, reflecting an adaptive behavioral adjustment to persistent human disturbance (Mainini et al., 1993; Neuhaus & Mainini, 1998; Louis & Le Beere, 2000; Griffin et al., 2007; Li et al., 2011; Greulich, 2015; Cheng et al., 2021).

4. Material and methods

4.1 Study site

The study was conducted in the Mont Avic Natural Park (MANP), located in the Aosta Valley region of northwestern Italy (Fig. 2). Established in 1989 to preserve the upper basin of the Chalamy stream in the municipality of Champdepraz, the park initially covered 5,747 ha. It was expanded in 2003 to include the Champorcher Valley and in 2023 to the upper Val Clavalité in the municipality of Fénis, bringing the total park area to approximately 7,300 ha (73 km²), with elevations ranging from 1,000 m to 3,185 m at the summit of Mont Glacier. The MANP has been designated as a Special Conservation Site (IT1202000 - Parco Naturale Mont Avic) and is also part of the Special Protection Area IT1202020 - Mont Avic and Mont Emilius within the EU Natura 2000 Network (Council of the European Communities, 1979, 1992).

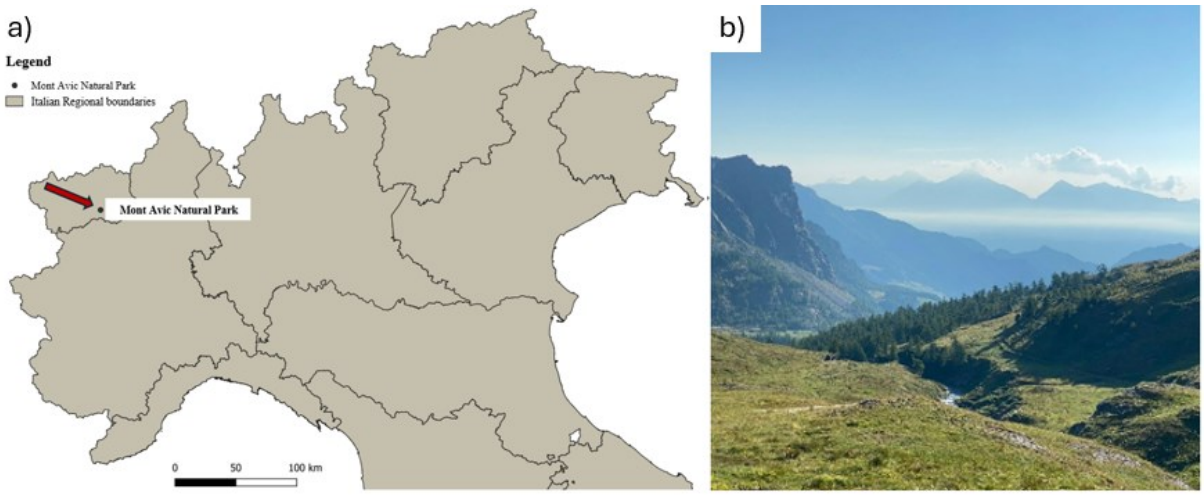

Figure 2. Territorial overview of the Mont Avic Natural Park in northern Italy (a). Photograph taken during the summer 2024 fieldwork, depicting the study area within the park (b).

The climate of MANP is predominantly alpine, with relatively low levels of precipitation (on average 800- 1200 mm/year). As altitude increases, the climate becomes harsher, with colder temperatures, stronger winds, and significant snowfall (Mont Avic Natural Park, 2024; Mercalli, 2003). Water bodies represent the 3% of the total area of the Park, with around thirty ponds of glacial origin and two main watercourses: the Chalamy torrent in the Champdepraz district and the Ayasse torrent in the Champorcher district (Bocca et al., 2009).

From a geological standpoint, the MANP is characterized by the predominance of ophiolitic complexes and high-grade metamorphic rocks, primarily gneiss. The vegetation is influenced by the park's geology, particularly the extensive presence of ophiolitic complexes, which give

rise to shallow, nutrient-deficient soils rich in heavy metals (Verger et al., 1993; D'Amico et al., 2005; Bocca et al., 2009). Forests cover 27% of the Park and are composed by natural alpine and sub-alpine broad-leaf and coniferous forests. The park contains Italy's largest Hooked Pine *Pinus uncinata* forest, covering over 1,100 hectares (Cremonese et al., 2015), and includes seed-production forests that are managed for conservation purposes by the regional forestry authority. This conifer thrives on the acidic soils derived from ophiolitic rocks and is often replacing more widespread conifers such as larch *Larix decidua* and spruce *Picea abies* (Verger et al., 1993; Mont Avic Natural Park, 2024). The wildlife of MANP is typical of alpine ecosystems. Mammals such as chamois *Rupicapra rupicapra*, ibex *Capra ibex*, and red deer *Cervus elaphus* are present in the park's meadows and forests. The Alpine marmot, which is the focus of this study, is also commonly found in the alpine meadows and open areas of the park along with its main natural predators in the area: the golden eagle *Aquila chrysaetos* and the red fox *Vulpes vulpes* (Mont Avic Natural Park, 2024). In addition to its terrestrial ecosystems, the park is home to numerous glacial lakes and wetlands. The lakes serve as habitats for diverse aquatic species, including zooplankton species, with greater taxonomic richness in fish-free lakes. Introduced fish, including *Salvelinus alpinus* and *Salmo trutta*, significantly altered these aquatic ecosystems, impacting native amphibians such as the mountain frog *Rana temporaria*, which breed primarily in fish-free waters due to predation pressures (Tiberti & Brighenti, 2019).

Mont Avic Natural Park promotes tourism with a strong focus on environmental awareness and preservation. The park features two visitor centers: one in Covarey (45.69854, 7.68902), which offers interactive displays on rock formations, wetlands, and forests, alongside a multipurpose hall for educational events; and another at Villa Biamonti in Champorcher (45.62931, 7.70245), a building restored with eco-friendly materials that showcases the geology, morphology, and high-altitude environments of the park. The most recent visitor data (Fig. 3), updated in 2022, show that attendance at the Covarey and Champorcher centers has increased, with weekday visits rising steadily from 3,424 in 2020 to 3,662 in 2022, and holiday attendance also growing, reaching 1,545 visits in 2022 (Dichiarazione Ambientale EMAS, 2021-2023). This trend reflects growing interest in eco-tourism and the park's successful outreach efforts. Tourist facilities include various accommodations: five structures between refreshments and mountain huts, and approximately 96 kilometers of marked trails. However, visitors are required to follow strict regulations to minimize environmental impact, such as staying on designated paths, avoiding disturbances to wildlife, and refraining from littering or collecting natural materials (Mont Avic Natural Park, 2024).

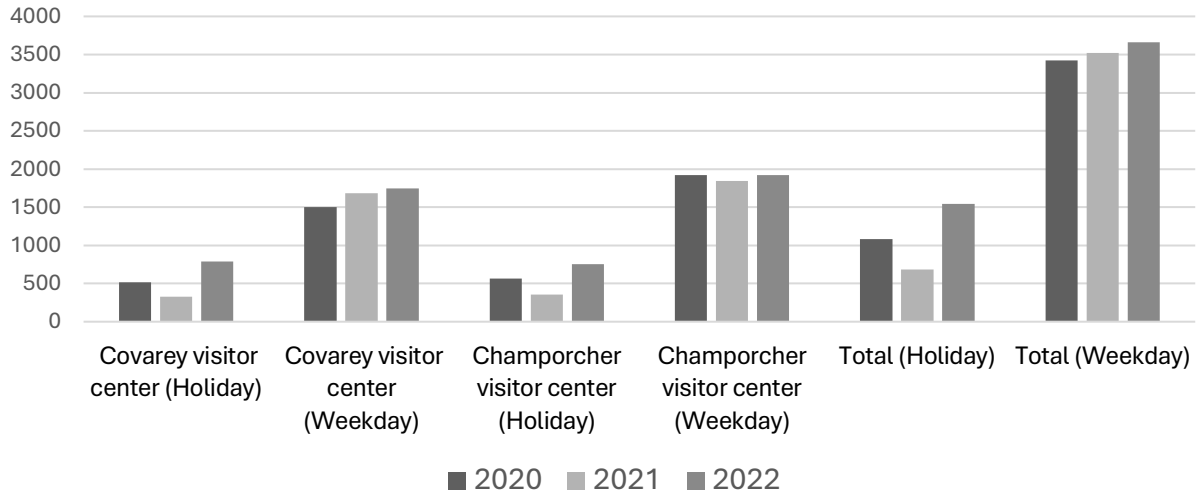

Figure 3. Number of visitor of the Covarey and Champorcher visitor centers from 2020 to 2022, data retrieved from the Dichiarazione Ambientale EMAS, 2021-2023 (MANP).

4.2 Sampling sites

Two distinct study areas were selected in the Valley of Champorcher for data collection (Fig. 4): one with restricted access to the public and one that experiences regular tourist activity.

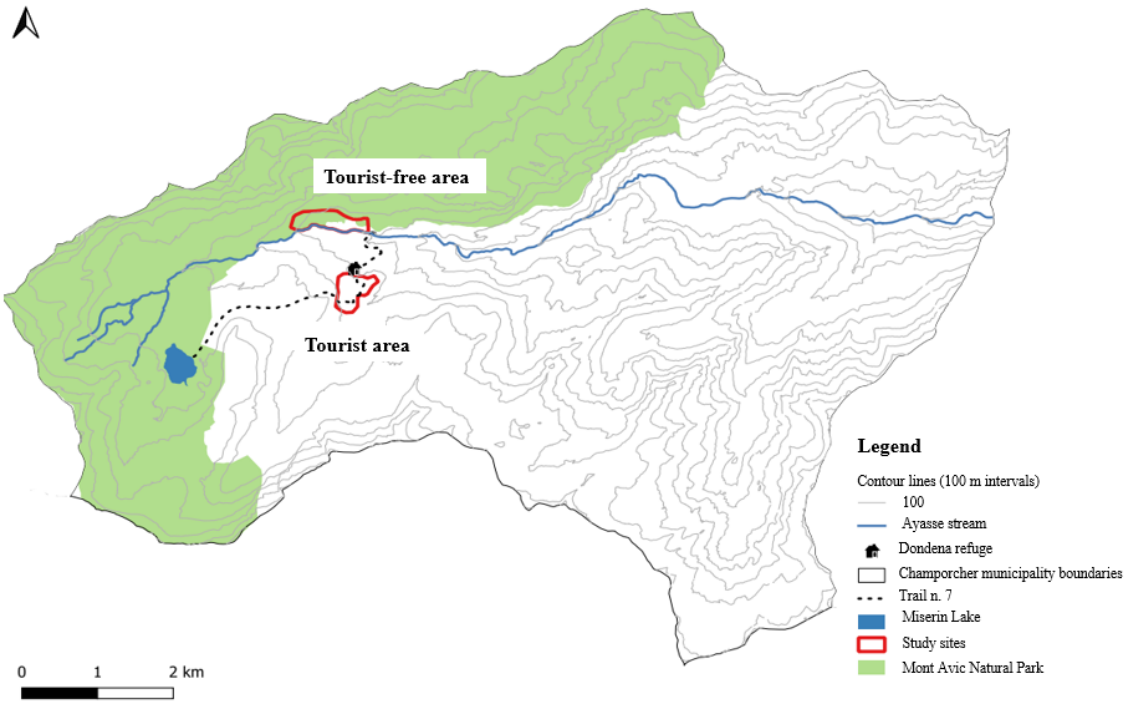

Figure 4. Geographical context of the two study sites selected for the analysis of flight initiation distance (FID) variation in relation to tourist presence in a populatio of Alpine marmots in Mont Avic Natural Park during the summer of 2024.

To allow the isolation of tourist presence as the principal variable influencing marmot behaviour, the two areas were selected to feature similar characteristics in terms of geomorphological structure and vegetation composition.

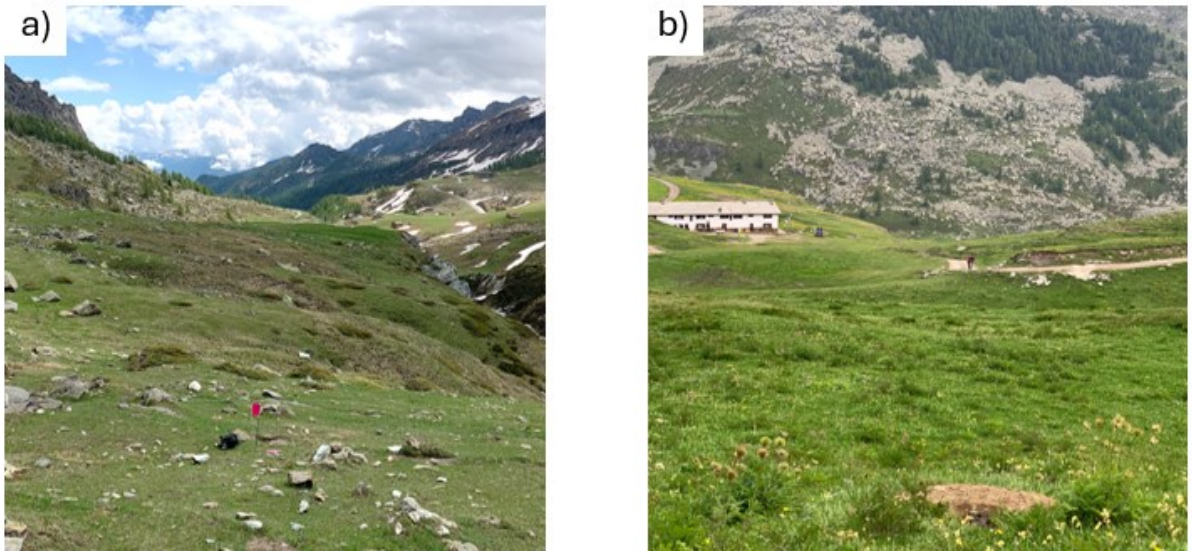

Figure 5. Study sites located in the Mont Avic Natural Park: the first with restricted access to tourists, on the left side of the Ayasse stream visible in the picture (a) and the second near trail number 7 and the Dondeina refuge, both visible in the image (b).

The first area (Fig. 5a), characterized by the absence of tourists, is situated on the right bank of the Ayasse River (45.617810, 7.546374). This area is accessible only to park rangers. The second study area (Fig. 5b), located near the Dondena refuge along the popular hiking trail No. 7 (Dondena-Bèse-Lac Miserin), lies on the left bank of the Ayasse River (45.610047, 7.550380).

The Dondena refuge, situated at an elevation of 2,189 m, is a historical building originally built in the 19th century as a hunting lodge. Today, it serves as a popular destination for hikers and trekkers exploring the Champorcher Valley, offering accommodation and a base for excursions into the surrounding mountains. The refuge is typically open from June to September and can host up to 80 people, providing basic facilities for visitors during the peak summer season. The refuge also includes a winter shelter available for 9 guests.

Both study areas span approximately 0.3 km^2 and are located at similar elevations, ranging between 1,800 and 2,500 m above sea level. They share comparable characteristics in terms of morphology and vegetation, consisting primarily of open, gently sloping plateaus suitable for grazing, with a mix of alpine meadows featuring open habitats and scattered patches of shrublands. The two areas are separated by an approximate straight-line distance of 500 m, however the proximity of the sites does not pose an issue, as movement of marmots is restricted by the natural barrier formed by the Ayasse River, effectively isolating the populations.

4.3 Data collection

Data for this study were collected between June 11 and September 3, 2024, for a total of 23 sampling days. During this period, I conducted data collection approximately 2 to 3 days per week. The daily observations were carried out between 6 a.m. and 4 p.m., a time frame chosen to coincide with the peak activity periods of marmots (Armitage and Salsbury, 2015). Marmots are most active during the cooler parts of the daylight hours, specifically during the morning and late afternoon, and reduce activity during the hottest hours to conserve energy and avoid heat stress (Armitage and Salsbury, 2015). A total of 236 Flight Initiation Distance (FID) tests were performed on unmarked individuals and each FID test followed a standardized protocol. While it was not possible to guarantee that the same individual was not observed more than once, I took precautions to minimize this risk, such as varying the location and time of the observations. As a result, the likelihood of repeated measurements on the same animal was reduced. When a marmot was spotted, and it was confirmed that the animal was not in a heightened state of alert (i.e., it was not vigilant or emitting alarm calls), I placed a flag to mark the starting distance (initial distance between the observer and the marmot). From this point, I walked toward the marmot at a constant speed of approximately 0.5 m/sec. This slow, steady approach allowed for a consistent measure of FID across all trials. I continued walking toward the marmot until the animal initiated flight, which was defined as the moment when the marmot moved a distance at least equal to the length of its body. At this point of flight, I placed a second flag to mark the flight initiation distance (FID), representing the distance between the observer and the marmot at the moment it decided to flee. Since marmots generally retreat to a burrow when threatened (Armitage, 1962), I also proceeded to identify the burrow into which the marmot had fled. I then took measurements of the starting distance, flight distance, and distance to burrow (in m) directly from the marmot's location using a laser rangefinder (Bushnell Fusion 1600 ARC).

In addition to these three distances, other data were systematically recorded to be used as covariates in the statistical model, which helped explain the variability observed in FID (Fig. 6). Alongside the primary variable of interest—the presence or absence of tourists in the two distinct study sites—the following data were collected:

1. Date and time: the date and specific time of each observation were recorded to analyze temporal patterns in marmot activity and FID. Marmots are diurnal animals with a bimodal activity pattern, showing peak activity in the early morning and late afternoon.

This activity pattern is strongly influenced by temperature, as marmots tend to avoid the midday heat by limiting foraging and other activities during warmer periods. By focusing on observations made during these cooler periods, when marmots are most active, it was possible to capture behaviors related to natural foraging and alertness, minimizing potential behavioral bias due to temperature-related inactivity. Recording the date also allowed for the analysis of any seasonal variations in marmot FID across the study period (Armitage and Salsbury, 2015).

2. Substrate type: the type of substrate in which the marmots were located was classified using a scale: 1 for low vegetation (marmot in open area), 2 for high vegetation (marmot covered by vegetation), 3 for dirt, 4 for stones, and 5 for talus. The different substrates may affect the ease with which marmots can escape and the likelihood of their detection by observers.

3. Weather conditions: weather conditions can influence visibility, perception, and risk assessment of marmots and therefore have an influence on FID. Clear skies enhance visibility, allowing marmots to detect predators at greater distances and typically resulting in longer FIDs. Conversely, cloud cover, precipitations and wind may reduce auditory and visual detection, leading to shorter FIDs as threats are perceived later (Zaman et al., 2019). Meteorological factors were recorded as follows:

    - Cloud cover: a scale from 0 to 100% indicated the extent of cloud coverage, providing context for visibility conditions.

    - Wind: wind strength was classified on a scale from 0 to 3, where 0 indicated no wind, 1 a breeze (with leaves and small twigs constantly moving and light flags extended), 2 moderate wind (with larger tree branches moving and whistling in wires), and 3 strong wind (with whole trees moving and noticeable resistance felt when walking against the wind).

    - Precipitation: precipitation levels were recorded on a scale of 0 to 2, where 0 represented no precipitation, 1 indicated a drizzle and 2 actual rain.

4. Presence of conspecifics: data on the presence of conspecifics within 1, 5, and 10 meters of each focal marmot were recorded, as the proximity of other marmots is known to influence FID. Marmots foraging near conspecifics tend to have shorter FIDs due to a heightened sense of safety, likely stemming from shared vigilance and reduced individual risk perception within the group (Monclús et al., 2015).

5. Behavior of the animal: limited data exist on how current behaviors affect FID, with most studies focusing specifically on foraging. Foraging is directly tied to fitness, yet it may increase perceived risk due to the head-down posture and potential distance from burrows. Consequently, foraging marmots often show shorter FIDs, possibly due to heightened vulnerability despite the high cost of interrupted foraging during the brief summer season (Brown, 1999; Fortin et al., 2004; Blanchard and Fritz, 2007; Giari, 2022). Specific behaviors were categorized as follows:

   - Sit: the marmot had its head tilted upwards, looking around while seated on 'four legs' or 'two legs' (not in a vigilance position) on the ground.
   - Forage: the marmot exhibited a ‘head-down’ posture with occasional rapid vigilance events (head up).
   - Lie: the marmot lay on the ground, showing a 'head-up' posture along with rapid vigilance events.
   - Groom: the marmot brushed and cleaned its coat, maintaining a 'head-up' posture with rapid vigilance events.

Mont Avic 2024	FLIGHT INITIATION DISTANCE TEST																				
ID_FIDTEST																					
Data																					
Weather	clouds	wind	Precip.	clouds	wind	Precip.	clouds	wind	Precip.	clouds	wind	Precip.	clouds	wind	Precip.	clouds	wind	Precip.	clouds	wind	Precip.
Time																					
Conspecifics	r = 1 m	r = 5 m	r = 10 m	r = 1 m	r = 5 m	r = 10 m	r = 1 m	r = 5 m	r = 10 m	r = 1 m	r = 5 m	r = 10 m	r = 1 m	r = 5 m	r = 10 m	r = 1 m	r = 5 m	r = 10 m	r = 1 m	r = 5 m	r = 10 m
Behaviour																					
Dis. Start Pos.																					
Dis. Flight																					
Substrate																					
Dis. burrow																					

Figure 6. Example of a checksheet use for data collection during the flight initiation distance test on Alpine marmots in Mont Avic Natural Park, in summer 2024.

To assess tourist presence throughout the study season, data were gathered using a people counting device located at Miserin (45.601083, 7.515604). Although this counter is positioned outside the immediate study area, it is directly linked to trail number 7, which traverses the study area itself. To ensure the reliability of these data as a proxy for tourist presence, the counter data were cross-referenced with direct observations recorded by park rangers within the study site. A correlation analysis was conducted, and the results indicated that the data from the Miserin counter effectively represent tourist influx within the study area over the course of the season.

4.4 Data manipulation

The data collected during the study were organized in an Excel spreadsheet (Fig.7). Each row in the spreadsheet represented a single FID test, while each column corresponded to a specific variable or measurement taken during the observation. In addition to the variables already described in the "data collection" section, the following data were reported in the dataset:

ID_fidtest: A unique identifier assigned to each test to distinguish individual observations. The IDs were coded to indicate the specific study area (NT for non-tourist or T for tourist) and the sequence number of the test.

Julian_date: The Julian calendar date, which represents the day of the year the observation took place.

Tourist_presence: A binary variable indicating the presence (1) or absence (0) of tourists during the observation.

Time_of_day: A categorical variable indicating whether the observation was made in the morning, at noon, or in the afternoon.

ID_fidtest	date	julian_date	tourist_presence	time	time_of_day	substrate	clouds
Pma_FID_NT_1	11/06/2024	163	0	12:06	noon	1	0,5
Pma_FID_NT_2	11/06/2024	163	0	12:15	noon	1	0,5
Pma_FID_NT_3	11/06/2024	163	0	12:26	noon	1	0,5
Pma_FID_NT_4	11/06/2024	163	0	12:31	noon	1	0,5
Pma_FID_NT_5	11/06/2024	163	0	13:20	afternoon	1	0,5

wind	prec	consp_1	consp_5	consp_10	behaviour	dist_start	dist_flight	dist_burrow
1	0	0	0	0	sit	50	43	10
1	0	0	0	0	sit	37	23	22
1	0	0	0	1	groom	33	23	0
1	0	0	1	0	sit	31	24	2
1	0	0	0	0	forage	51	47	27

Figure 7. Example of the Excel spreadsheet used to store the dataset derived from field measurements conducted during the analysis on marmots FID in the Mont Avic Natural Park in 2024.

For the second part of the analysis, an additional Excel spreadsheet was created to record data specific to the study area with tourist presence (Fig.8). The recorded variables remained consistent with those used in the previous dataset, with the exception of tourist_presence. Instead of a binary indicator, this variable was replaced by the daily count of tourists observed in the area, n_tourists.

ID_fidtest	date	julian_date	n_tourists	time	time_of_day	substrate	clouds
Pma_FID_T_1	12/06/2024	164	0	9.11	morning	1	0,6
Pma_FID_T_2	12/06/2024	164	0	9.23	morning	1	0,6
Pma_FID_T_3	12/06/2024	164	0	9.43	morning	1	0,4
Pma_FID_T_4	12/06/2024	164	0	10.10	morning	1	0,5
Pma_FID_T_5	12/06/2024	164	0	10.29	morning	3	0,5

wind	prec	consp_1	consp_5	consp_10	behaviour	dist_start	dist_flight	dist_burrow
1	0	0	1	2	forage	103	85	5
1	0	0	0	0	sit	52	48	1
1	0	0	0	0	sit	25	17	0
1	0	0	0	2	sit	60	31	0,2
1	0	1	1	0	play	59	50	23

Figure 8. Example of the Excel spreadsheet used to store the dataset derived from field measurements conducted during the analysis on marmots FID in the Mont Avic Natural Park in 2024, specifically within the study area with tourist presence, close to the Dondena refuge.

4.5 Data analysis

The statistical analyses for this study were conducted with R 4.2.2 (www.r-project.org) in RStudio (www.rstudio.com). The analysis was conducted in two phases, each examining a distinct dataset to explore variations in FID under different conditions. The first phase focused on the dataset comparing areas with and without tourist presence, while the second phase analyzed data specific to the study area with recorded daily tourist counts. After verifying the data accuracy, ensuring that all values were correctly recorded, checking for missing or anomalous data points, and confirming consistency across variables, I carried out an initial descriptive analysis to understand the distributional properties of each variable in the first dataset. This preliminary analysis, using summary statistics and visualizations, allowed me to identify the spread, central tendency, and potential outliers, providing insight into which data transformations or models might be suitable for further analysis. Since the raw FID data did not follow a normal distribution, an initial model was constructed with all explanatory variables, and a Box-Cox transformation was applied to determine an appropriate transformation. The "boxcocx" function, available in the 'MASS' package (Venables & Ripley, 2002), suggested a square-root transformation of the FID variable to better meet the assumptions of linearity, normality and homoscedasticity. Additionally, burrow distance was log-transformed to address the high variability and skewed distribution observed in its values. This transformation reduces the influence of large values and scales down the spread, allowing the model to better interpret and incorporate the effect of distances that vary widely. To avoid zero values, a constant of 0.1 (corresponding to the half of the lowest non-zero values) was added to all burrow distance values.

The core analytical approach was based on a global model, constructed as a multiple linear regression model. Linear regression is widely used to explore the relationship between a dependent variable and several predictors (Eberly, 2007). To examine whether FID was associated with tourist presence, I implemented a linear modeling approach using the "lm" function in R, where the square-root transformed FID was the response variable. The predictor variables included tourist presence, log-transformed burrow distance, starting distance, Julian date, marmot behavior at the time of observation, time of day, cloud coverage, wind intensity, and the number of conspecifics within 5 meters. These variables were selected based on a preliminary graphical exploration of the complete dataset, which identified them as both statistically and ecologically significant.

Model equation: FID ~ tourist presence + burrow distance + start distance + Julian date + behaviour + time of day + clouds + wind + conspecifics at 5 m.

Linear regression models assume a linear relationship between the predictors and the response variable, along with the assumptions of independence, normality of residuals, and homogeneity of variance. These assumptions were verified through diagnostic checks post-modeling on the model residuals. The "check_model" function from the 'performance' package was used to generate diagnostic plots for visual assessment of these assumptions (Lüdecke et al., 2021). Specifically, normality was assessed by inspecting the Q-Q plot of residuals, which should approximate a straight line if residuals follow a normal distribution. Homoscedasticity was checked by examining the scatterplot of residuals against fitted values, expecting a random spread around zero without clear patterns. Linearity was assessed through the same scatterplot, verifying that residuals were symmetrically distributed around the zero line across the range of fitted values. The purpose of creating this global model was to capture the collective effects of all potential covariates on FID, providing an overarching model structure from which it was possible to further refine or simplify through variable selection methods.

Before moving to model selection, multicollinearity among the predictor variables was assessed, as high multicollinearity can obscure the distinct effects of individual predictors and inflate standard errors, thus making it difficult to determine each variable's unique contribution. I began by inspecting correlations visually through the chart.correlation function from the 'PerformanceAnalytics' package (Peterson et al., 2018). This function provides a pairwise plot of correlations between predictors, offering an initial look at whether any variables are highly correlated with one another; values above |0.7| are considered indicative of high collinearity. While useful for detecting general trends, beside inspection of correlation coefficients, I proceeded to calculate the Variance Inflation Factor (VIF) for each predictor variable in the model. VIF, accessed via the "vif" function from the 'car' package (Fox and Weisberg, 2019), quantitatively measures multicollinearity by examining how much the variance of a coefficient is inflated due to linear dependencies among predictors. VIF values exceeding 3 are generally considered to indicate moderate multicollinearity, while values over 10 suggest severe multicollinearity, potentially requiring variable removal. In the model, all VIF values were below 3, indicating that multicollinearity was unlikely to affect the results adversely, allowing to retain all covariates in the global model for the initial stage of the analysis.

The next step was to simplify the global model to identify the most informative subset of variables while reducing complexity. For this purpose, I employed a stepwise selection

approach using the “step” function, which iteratively tests models by adding or removing predictors based on statistical criteria, specifically the Akaike Information Criterion (AIC). AIC provides a measure of model fit that penalizes for the number of parameters, balancing model complexity and explanatory power. Lower AIC values indicate a more parsimonious model, suggesting a better balance between goodness-of-fit and model simplicity (Whittingham et al., 2006). The stepwise selection process began with the global model as the initial input. The function evaluated each predictor variable, testing the effect of removing or adding it to the model at each iteration and retaining only the variables that consistently improved or maintained model fit based on AIC criteria. Finally, to interpret the effects of the remaining variables on FID, the results have been visualized using the ‘visreg’ package (Breheny and Burchett, 2017).

The second phase of data analysis was conducted on the dataset specific to the study area with tourist presence and the same modeling procedure was applied, following the steps of data transformation, global model construction, and model simplification as with the first dataset.. In this dataset, the variable n_tourists was used to represent the daily number of tourists observed, replacing the binary tourist_presence variable from the previous analysis.

As with the initial model, FID was square-root transformed, and burrow distance was log-transformed to address its skewed distribution and enhance model fit. Following the correlation analysis of the variables, conducted both visually and through Variance Inflation Factor (VIF) calculations, n_tourists and julian_date were found to be correlated, with VIF values exceeding the threshold of 3. Based on this observation, the global model was constructed to mitigate multicollinearity by excluding Julian date while retaining the same predictor variables as in the first analysis, with n_tourists replacing tourist_presence.

Model equation: FID ~ number of tourists + burrow distance + start distance + behaviour + time of day + clouds + wind + conspecifics at 5 m.

After applying the stepwise selection procedure, the model’s effects on FID were again visualized using the ‘visreg’ package.

5. Results

5.1 Tourist presence vs. tourist absence

The analyses performed on the first dataset, which includes the binary variable for tourist presence or absence, revealed that the model adequately described the data. Verification of model assumptions and diagnostic criteria showed no substantial deviations from linearity or homoscedasticity, and multicollinearity among predictors was within acceptable limits. While there was a normality assumption violation, this deviation did not impact the model (Fig. 9).

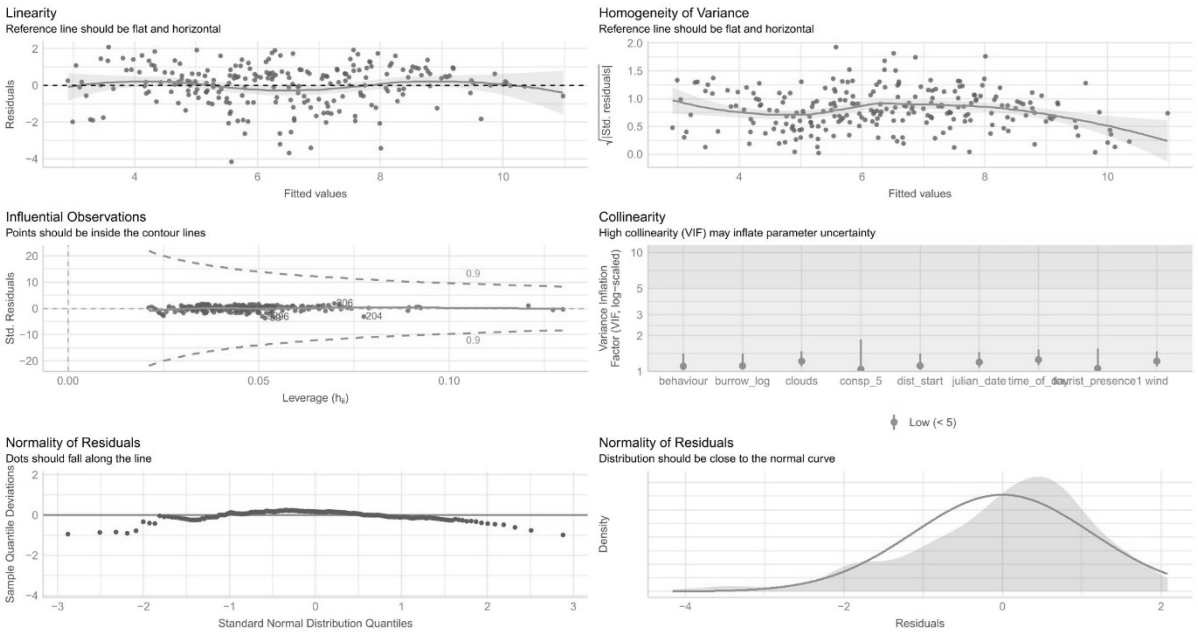

Figure 9. Diagnostic plots assessing linearity, homoscedasticity, absence of influential observations, multicollinearity, and normality of residuals for the initial model describing the relationship between square-root transformed flight initiation distance (FID) and various predictor variables in a population of Alpine marmots within two study sites in the Mont Avic Natural Park in 2024.

Based on this model, it is possible to state that flight initiation distance (FID) was best explained by tourist presence (Fig. 10, Table 1), burrow distance, and start distance (Fig. 11, Table 1).

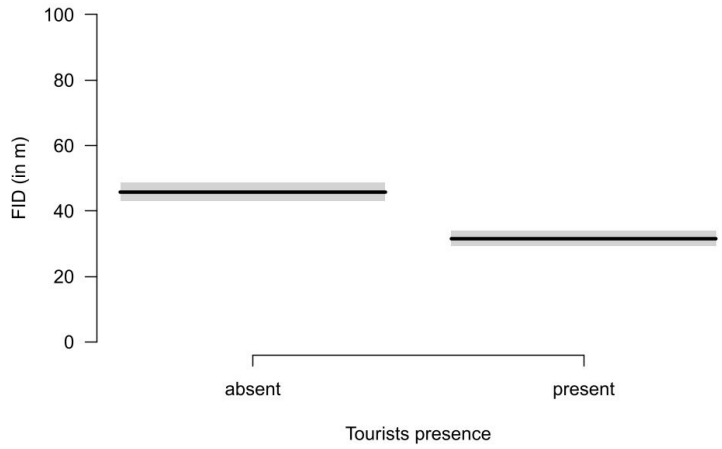

Figure 10. Distribution of flight initiation distance (FID) of individuals exposed and non exposed to the presence of tourists in a population of Alpine marmots within two study sites in the Mont Avic Natural Park in 2024. The Median is indicated as a horizontal black line.

Specifically, parameter estimates of the selected model showed a significant positive relationship between start distance and FID, as well as between burrow distance and FID. Additionally, FID was about 15 m lower in the presence of tourists than in their absence, indicating that the presence of tourists influences the FID of marmots in the study area.

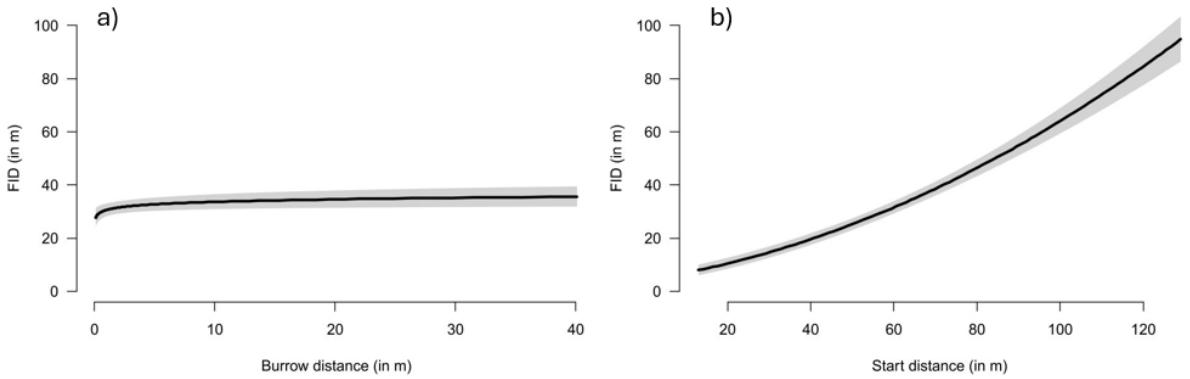

Figure 11. Marginal effects of burrow distance (a) and start distance (b) on the flight initiation distance (FID) in a population of Alpine marmots within two study sites in the Mont Avic Natural Park in 2024. The grey-shaded bands represent the 95% confidence interval.

Table 1. Estimates of the first model selected to explain the variation in square-root transformed flight initiation distance (FID) in a population of Alpine marmots within two study sites in the Mont Avic Natural Park in 2024. The table provides, for each parameter, the regression coefficient estimate, standard error (SE), and the 95% confidence interval with its lower (LCL) and upper (UCL) bounds.

Parameter	Estimate	SE	LCL	UCL
Intercept	2.98	0.22	2.55	3.41
Burrow distance [log]	0.02	0.01	0.00	0.04
Start distance	0.06	< 0.01	0.05	0.07
Tourists presence	−1.14	0.15	−1.43	−0.84

5.2 Effect of tourist abundance

The model built on the second dataset, which includes the variable for daily tourist counts, was found to be suitable for describing the data. Verification of assumptions and diagnostic checks confirmed that residuals met the criteria for linearity, homoscedasticity, and multicollinearity among predictors. As in the previous model, there is a violation of the normality assumption, which again does not affect the predictions (Fig. 12).

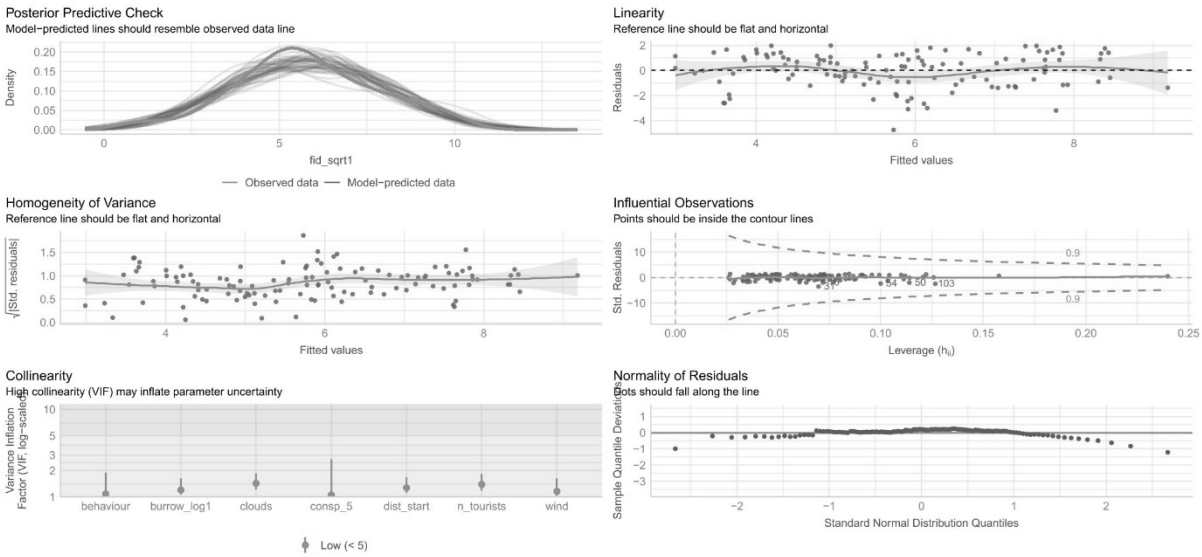

Figure 12. Diagnostic plots assessing linearity, homoscedasticity, absence of influential observations, multicollinearity, and normality of residuals for the initial model describing the relationship between square-root transformed flight initiation distance (FID) and various predictor variables in a population of Alpine marmots exposed to touristic presence in the Mont Avic Natural Park in 2024.

The daily count of tourists, initially included in the model to evaluate its influence on FID within the tourist area, was not retained in the final model (Table 2). This outcome indicates that the data provide insufficient evidence for the effect of increasing tourist numbers on FID in marmots over the summer season (Fig. 13).

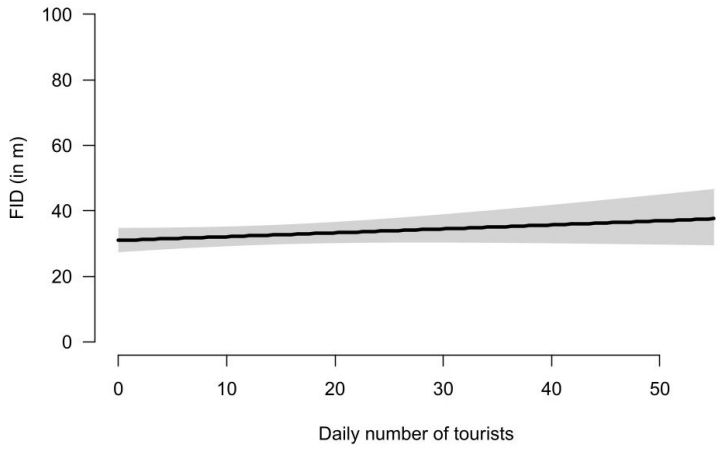

Figure 13. Marginal effect of tourist presence, calculated as the daily number of tourists, on square-root transformed flight initiation distance (FID) in a population of Alpine marmots within two study sites in the Mont Avic Natural Park in 2024.

The final model identified burrow distance and starting distance as the only predictors with a significant effect on FID. Both variables exhibited a positive relationship with FID, indicating that flight initiation distance increases as burrow distance and starting distance become greater (Fig. 14).

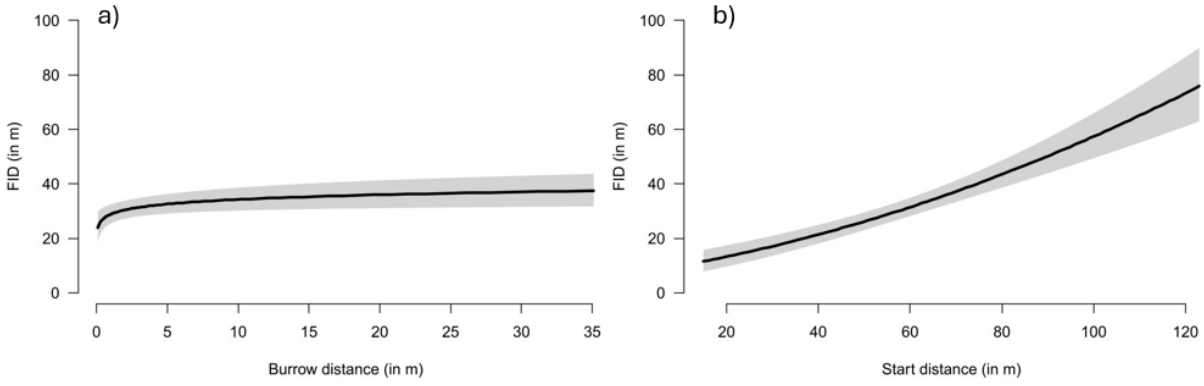

Figure 14. Marginal effects of burrow distance (a) and start distance (b) on square-root transformed flight initiation distance (FID) in a population of Alpine marmots exposed to tourists presence in the Mont Avic Natural Park in 2024. The grey shaded bands represent the 95% confidence interval.

Table 2. Estimates of the second model selected to explain the variation in square-root transformed flight initiation distance (FID) in a population of Alpine marmots exposed to tourists' presence in Mont Avic Natural Park in 2024. The table provides, for each parameter, the regression coefficient estimate, standard error (SE), and the 95% confidence interval with its lower (LCL) and upper (UCL) bounds.

Parameter	Estimate	SE	LCL	UCL
Intercept	2.37	0.35	1.68	3.06
Burrow distance [log]	0.21	0.07	0.06	0.36
Start distance	0.05	0.01	0.04	0.06
Tourists number	0.01	0.01	−0.01	0.03

6. Discussion

This study investigated the behavioral responses of alpine marmots to human presence, specifically assessing variations in FID under different levels of tourist activity. The results showed that FID was lower in the tourist area compared to the non-tourist area. However, the daily count of tourists included as a variable in the second dataset did not show a significant influence on FID. FID was significantly influenced by starting distance and burrow distance; marmots were more likely to flee at greater distances when further from their burrow or when the starting distance of the observer was larger.

The significant difference in FID between the tourist and non-tourist areas aligns with findings from previous studies, supporting the hypothesis that habituation occurs in wildlife exposed to frequent human activity (Samia et al., 2015; Mbise et al., 2020). In my study, marmots in the tourist area exhibited lower FID, a pattern consistent with other research on marmot species showing that repeated exposure to non-threatening human presence reduces the perceived risk and, consequently, the intensity of escape responses (Neuhaus & Mainini, 1998; Cheng et al., 2021). However, the role of behavioral plasticity in shaping FID warrants further discussion. Behavioral plasticity refers to an organism's capacity to modify its behavior in response to environmental stimuli, resulting from the interplay of genetic predisposition and learning (Mery & Burns, 2010). Studies indicate that some species adjust their escape responses depending on the type and intensity of human activity. For instance, harmless human presence, such as recreationists, often facilitates habituation (Uchida et al., 2022), while consumptive human activities like hunting tend to elicit heightened escape responses, as observed in red deer *Cervus elaphus* during hunting seasons (Meisingset et al., 2022).

In this study, marmots demonstrated a measurable difference in FID between areas with and without tourist presence, suggesting that habituation to humans plays a more prominent role compared to other factors. While behavioral plasticity allows for adaptation to immediate changes in the environment, it has inherent costs and limitations (DeWitt et al., 1998; Murren et al., 2015). Moreover, the interplay between short-term learning and long-term evolutionary processes in marmot escape behaviors remains unclear. Prior research in yellow-bellied marmots *Marmota flaviventris* has demonstrated a decrease in FID with repeated human approaches over a 15-year study period (Uchida and Blumstein, 2021), suggesting that long-term exposure is a critical factor in shaping escape responses. Although the current study lacks

longitudinal data, the significant differences in FID between tourist and non-tourist areas hint at similar processes of habituation in Alpine marmots in the Mont Avic Natural Park.

While habituation was evident in the binary comparison of tourist presence versus absence, the intensity of tourist pressure, represented by daily tourist counts, was not a significant predictor of FID. This contrasts with findings from other studies, which documented a correlation between increased human activity and reduced FID (Mainini et al. 1993; Neuhaus and Mainini 1998). A possible explanation for this discrepancy could lie in the relatively short time frame of this study, which may have been insufficient to capture behavioral adjustments to varying levels of tourist activity. It is also possible that the marmots' habituation threshold was already reached, resulting in a generalized tolerance to human presence regardless of variations in tourist density.

The strong influence of starting distance on FID observed in this study aligns with findings reported in the literature across various taxa, where starting distance is frequently identified as a major predictor of FID variation. The positive relationship between starting distance and FID is well-documented and reflects the balance between the costs and benefits of escape decisions. As starting distance increases, the costs of monitoring an approaching predator also rise, making earlier flight a more favorable strategy to minimize potential risks (Blumstein, 2003). Similarly, burrow distance emerged as a significant predictor of FID in this study, with marmots fleeing at greater distances when located farther from their burrow. This finding aligns with the principles of optimal escape theory, which suggests that animals adjust their escape behavior based on the proximity to a refuge, balancing the costs of fleeing with the perceived risk of predation. The fitness trade-offs between fleeing and remaining are influenced by distance to a refuge, as the probability of successful predation—and thus the costs of remaining—decreases when prey can reach safety more quickly (Ydenberg and Dill, 1986; Monclús et al., 2015). When marmots are farther from their burrow, they experience heightened vulnerability, leading to increased vigilance and an elevated likelihood of earlier flight in response to potential threats. Similar patterns have been documented in other studies across various burrowing rodent species (Bonenfant and Kramer, 1996; Dumont et al., 2012; Monclús et al., 2015; Zaman et al., 2019).

7. Conclusions and future developments

This study aimed to advance knowledge of human-wildlife dynamics within alpine ecosystems, providing data on the behavioral flexibility of marmots in response to tourism pressure. While data suggested that the presence of tourists had a clear impact on marmot escape behavior, it does not provide conclusive evidence that human activity negatively influences marmot fitness or population dynamics. To comprehensively assess the impact of tourism on marmot populations, future studies should incorporate physiological and demographic data. For instance, measuring stress hormone levels (e.g., glucocorticoid levels) and monitoring physical parameters such as body weight could provide insights into the physiological costs of human disturbance. Longitudinal studies tracking population trends over time would also be essential to understand whether habituation is accompanied by demographic stability or decline. Behavioral habituation, as observed in the tourist area, may allow marmots to conserve energy by reducing unnecessary flight responses. However, the long-term consequences of such adjustments remain uncertain. Habituation may mask underlying stress or reduced reproductive success. Without comprehensive physiological and demographic data, management decisions should not rely solely on observed behavioral changes, as this puts at risk of either unnecessary restrictions on human activities or underestimations of disturbance impacts (Klein et al., 1996; Papouchis et al., 2001).

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