University of Freiburg

Faculty for Environment and Natural Resources

Department of Biometry and Environmental System Analysis

Seasonal habituation to human activities in alpine marmots (*Marmota marmota*) in the Gran Paradiso National Park, Italy

Bachelor of Science thesis of

Julia Greulich

Supervisor: Dr. Simone Ciuti

Co-supervisor: Prof. Dr. Ilse Storch

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Declaration

This thesis was written in the faculty of environment and natural resources of the University of Freiburg, in the department of biometry and environmental analysis from the 12th of June to the 12th of September 2015 under supervision of Dr. Simone Ciuti.

I, Julia Greulich, hereby declare, that I am the sole author and composer of my thesis and that no other sources or learning aids, other than those listed, have been used. Furthermore, I declare that I have acknowledged the work of others by providing detailed references of said work.

Place, date   Signature

Contents

1 Abstract

Extreme weather conditions and short vegetation periods minimize the time that alpine animals can spend on feeding and reproduction. Moreover high tourist numbers, and the associated human disturbance, in alpine regions can have a negative impact on the fitness level and reproduction rate of animals since fleeing has costs in addition to the benefits of reducing the risk of predation. Hence habituation is a good response by animals of not wasting energy and time that could have been spent on other vitally activities. We used alpine marmots (*Marmota marmota*) in the Gran Paradiso National Park, Italy, to understand seasonal habituation. Therefore we analysed flight initiation distances (FID, the distance at which an animal starts to flee from an approaching observer) in relation to the distance to different types of hiking trails in September 2014 and June 2015. We expected that FID would decrease the closer a marmot is being situated to a high frequented main track, because habituated animals show reduced flight distances. We created an analysis framework, using a generalized additive model, and found that: (1) FID is significantly lower the closer a marmot is being situated to a high frequented trail (2) there is no significant difference in FID of September 2014 and June 2015 (3) FID is significantly higher, if the den is between the marmot and the observer or on the side (4) FID is significantly lower at midday and (5) young individuals flee significantly later than adults. Marmots thus responded to some human disturbance by adjusting their flight behaviour. Lower FID close to high frequented trails lead to the assumption that those individuals are able to adapt to predictable human disturbance and therefore are habituated. Furthermore the level of habituation is comparable prior (September 2014) and after (June 2015) hibernation. These results should be taken into account when developing management plans for remote alpine areas. In addition our approach will be useful to show that the distance to the closest trail is, according to our results, the main driver for habituation.

Keywords: habituation, alpine marmot, *Marmota marmota*, Gran Paradiso National Park, FID, seasonal behaviour, human disturbance

2 Introduction

The Alps are one of the biggest and most important tourist regions in the world (BÄTZING, 2002) and alpine outdoor activities are very popular (e.g. AMMER, 1998; MARGRAF, 1999; STRASDAS, 1994). Even if the steady growth of alpine tourism stagnates since the 1980s (BÄTZING, 2002), remote alpine areas are being tapped in order to create new tourism potentials (MARGRAF et al., 1999). The technical development is moving forward very rapidly. From 1938 to 2000 the number of overnight stays in the Alps increased more than tenfold. More than 13 000 lifts and cableways are operating all over the year (AMMER, 1998). The negative consequence of this is the involved disturbance of wildlife. The more people are visiting alpine regions, the more trails and cableways are being established in remote areas in order to regulate the flow of visitors and the less habitat remains unaffected by tourists.

Previous studies found that human disturbance is a big issue for animals living in alpine regions (e.g. IMPERIO et al., 2013; INGOLD et al., 1993; INGOLD, 2005; LI et al., 2011; MILLER et al., 2011). Short vegetation periods and extreme weather conditions minimize the time that animals can spend on feeding and reproduction (MANINI et al., 1991; NEUHAUS et al., 1989). Especially hibernating animals such as alpine marmots (*Marmota marmota*) need to build up sufficient reserves of body fat during the short summer season in order to survive hibernation and for reproducing successfully the next year (BRUNS et al., 1999, MAININI et al., 1993). Therefore, every disturbance caused by humans can have a negative impact on the fitness and reproductive rate of animals (e.g. MAININI et al., 1993; MILLER et al., 2011; NEUHAUS et al., 1989). MANINI et al. (1993) already found that tourists and different hiking activities affect the behavioural response of alpine marmots. Their results show, for example, that marmots hardly ever took refuge in their burrow while experiments with trail hikers but escaped more often when they are confronted with a hiker with free-running dog. Since fleeing too soon means loosing time and energy that could be spent on other important activities, animals have to balance the costs and benefits of fleeing (KRAMER & BONENFANT, 1997; YDENBERG & DILL, 1986). Fleeing too late, however, is potentially lethal (KRAMER & BONENFANT, 1997). In most instances human disturbance does not involve a serious threat for animals. Hence, habituation is a good response by animals of not wasting energy and time. Habituated animals flee later and thus have more time and energy for feeding. The fitness level and reproduction rate of those animals is accordingly higher. Animals thus seem to be able to learn that humans are not necessarily a serious threat.

In our study, we used alpine marmots (*Marmota marmota*) to understand habituation. Marmots play an essential role in the alpine ecosystem and are a very common species in the Alps. Their preferred habitat are alpine meadows (ARNOLD, 1999). Especially in this habitat recreation has increased. If marmot colonies are minimized the hole predator-prey relationship is getting unbalanced (PELLICIOLI & FERRARI, 2013). As the Rifugio Vittorio Sella, which is located in our study area, is a popular place for hiking tourism in the summer season, we attempt to test whether human hiking activities and the distances to different types of hiking trails influence the seasonal habituation behaviour of alpine marmots in the Lauson area in the Cogne valley, Gran Paradiso National Park, Italy. Therefore, we analysed flight initiation distances (FID) of marmots in relation to the distance to different types of hiking trails, accordingly close to high frequented trails and in remote areas, in September 2014. FID is defined as the distance at which an animal is fleeing from an approaching human for the first time and should be optimized rather than maximized because, as indicated above, fleeing has costs in addition to the benefit of minimizing the risk of predation (YDENBERG & DILL, 1986). We expected that the FID would decrease the closer an individual is being situated to one of the main tracks. This, in turn, leads to the assumption, that marmots are habituated, because individuals with shorter FID are less afraid of humans and therefore adapted to disturbances.

As marmots hibernate, we repeated the study in June 2015 in order to test whether the habituation behaviour of marmots changed during wintertime. On the one hand, one could expect, that they are more afraid after hibernation because they did not see humans for a couple of months and are more timid because they are having youngs. On the other hand, other studies already found that memory is retained during hibernation in alpine marmots (CLEMENS et al., 2009) and consequently there would be no difference in the FID in early and late summer season.

Apart from the distance to the trail, the trail type and the season we included as well the following variables to our analyses. For the effect of age on FID we expected that young individuals flee later (= lower FID) because they are in general less experienced and more curious than adults (NEUHAUS & MANINI, 1998). As already oberserved by KRAMER & BONENFANT (1997) we tested if FID is higher, if the den is between the approaching observer and the individual and if a larger distance to the den leads to higher FID. Furthermore we included the direction of approach to our analyses to test the prediction that marmots flee later if the observer approaches from the bottom of a hill compared to approaches from top of a hill or in even terrain. Due to the results found by ARMITAGE (1962) we predicted that FID is lower at midday because he identified a peak of activity in the morning and in the afternoon in yellow bellied marmots (*Marmota flaviventris*). The analyses of the distance to the hut was made to see whether there is a general trend for FID being lower close to the hut. Elevation, land use, ground cover and the type of park zone were included as confounding factors when modelling the variability of FID.

Other studies concentrated on the effect of different hiking activities (MAININI et al., 1993), the distance to the den (BONENFANT & KRAMER, 1997), the position of the den (KRAMER & BONENFANT, 1997) and the age (NEUHAUS & MANINI, 1998) on the behaviour of alpine marmots and woodchucks (*Marmota monax*). Despite these previous studies, we additionally included the distance to the closest trail as the most meaningful variable to our analyses. The distance to the closest trail and the number of hikers using this trail is an important variable to show that animals in remote areas show a stronger response to human disturbance compared to individuals living close to high frequented trails. With this method it is possible to show that alpine marmots living close to high frequented trails adapted to human disturbance because of lower FID values, and therefore, are habituated.

3 Materials and methods

3.1 Study site

The study was carried out in the Lauson area, located in Cogne valley, Gran Paradiso National Park, Italy (45°34´ N, 7°18´ E) (see **Fig. 1**) (MASON et al., 2014). The study area contains a high density of alpine marmots (*Marmota marmota*). Other main vertebrate species that commonly occur in the park are ibex (*Capra ibex*), chamois (*Rupicapra rupicapra*) (BRAMBILLA & CANEDOLI, 2013, MASON et al., 2014) and the main natural predators of marmots, red foxes (*Vulpes vulpes*) and golden eagles (*Aquila chrysae*tos) (HÜTTMEIR et al., 1999; MAININI et al., 1993; PELLICIOLLI & FERRARI, 2013). Neither marmots nor the other species are under hunting pressure since the establishment of the Gran Paradiso National Park in 1922 (BRIVIO et al., 2015).

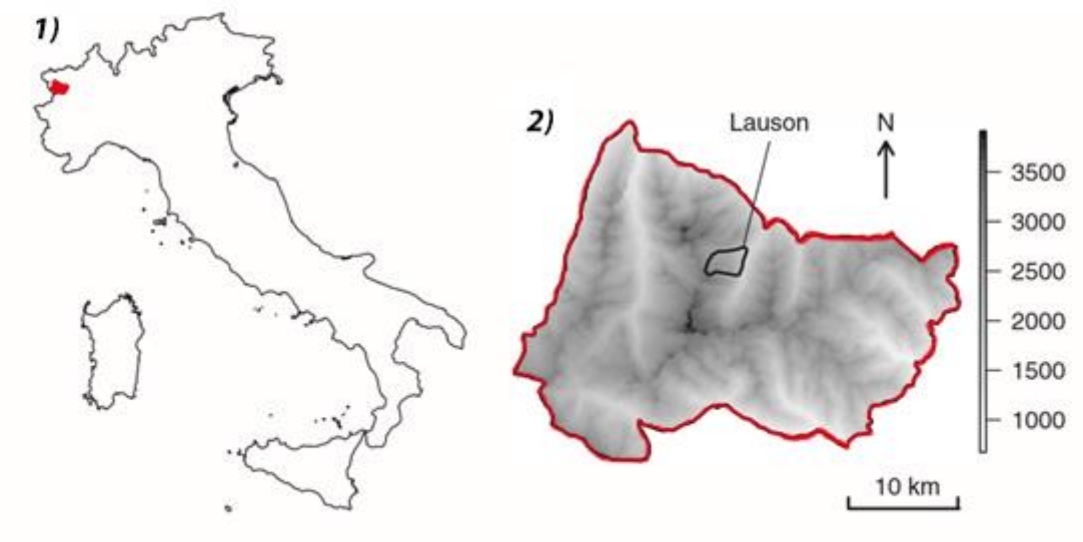

Fig. 1: Map of **1)** Italy, depicting the location of Gran Paradiso National Park in red, and **2)** displaying the location of the study area within the Gran Paradiso National Park. Shading indicates altitude in metres (from MASON et al., 2014, modified).

We collected data in an area of approximately 3.5 km² (3.5 km long, 1 km wide). The study area is characterised by grassland with scattered rocks, alpine meadows, screes and rock faces. The only way to the closest valley (Valsavarenche), from where other tourist can come from, is the Col de Lauson with an elevation of 3314 m (see **Fig. 2**) (BRIVIO et al., 2015; MASON et al., 2014).

The hut Vittorio Sella which is located in the study area is a popular place for hiking tourism in the summer season and can only be reached by foot. During the summer months the hut has a maximum of 160 overnight guests per night while the Gran Paradiso National Park is visited by about 2 million visitors per year. It has to be mentioned that the high number of tourist is concentrated to only a few valleys like the Lauson area. At the end of the season in September, marmots already experienced a few months with high tourist traffic. In comparison to that, there are almost no tourists in the early summer season in June when we did our second treatment after the hibernating animals woke up.

Fig. 2: Picture of the study area (June 2015). Rifugio Vittorio Sella (2588 m) can be seen in the front. The red arrow indicates the Col de Lauson (3314 m). Data was collected on both sites of the valley.

3.2 Data collection

We quantified habituation with FID because it "*is an easily measured quantitative indicator of* [an animals] *response to environmental disturbance*" (LIN et al., 2012, p. 31). As already mentioned by PETELLE et al. (2013) FID is defined as "*the distance at which an individual first flees from an approaching human*" (PETELLE et al., 2013, p. 1148). To assess seasonal habituation to hiking tourism in marmots, we conducted FID experiments on randomly chosen individuals in September 2014 and in June 2015.

We randomly walked around our study area in a group of two, approaching the marmots from different directions every time we returned to the same site. Marmots were not marked so we could not assure that the same individuals were not multiply sampled. Nevertheless, the circumstances (direction of approach, distance to trail, distance to den etc.) were different every time we did an approach. If the age category of an individual could not be clearly identified it was count as an adult to avoid an overestimation of young individuals. The vast majority of our approaches occurred off-trail.

When we spotted a marmot, the observer measured the starting distance with a range finder and approached the marmot with the same constant speed (approximately 2 km/h) along a straight line. Former studies by KRAMER & BONENFANT (1997) show that the walking speed of the approaching observer does not seem to affect the FID (KRAMER & BONENFANT, 1997), so we did not test FID for different approaching velocities. When the marmot showed a first reaction (e.g. lifting its head) to the approaching observer, the observer stopped and measured the distance to the individual. The observer kept on approaching until the marmot started to flee (see **Fig. 3**). At this point, the distance from the marmot to the observer, the FID, was recorded. All distances were measured with a TruPulse 360°B Laser Rangefinder.

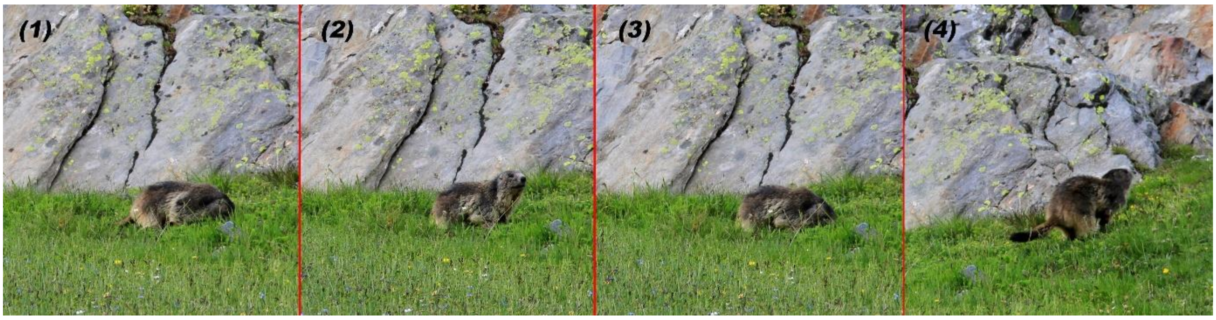

Fig. 3: Sequence of pictures showing the reaction of an alpine marmot to an approaching observer. **(1)** We spot the marmot and measure the start distance. Observer starts the approach. **(2)** Marmot showing a first reaction to the approaching observer by lifting its head. First reaction distance is measured. **(3)** Marmot still feels safe and continues feeding. **(4)** Observer came too close. Marmot is fleeing. FID is measured. Other parameters, e.g. den position, are recorded.

Furthermore, we recorded the following parameters:

- GPS-coordinates from the point where the marmots started fleeing
- Distance to the den from the point where the marmots started fleeing (if the marmot did not escape into a den, this value was set as NA)
- Position of the den: between us and the marmot, behind the marmot, den beside us and the marmot, marmot sitting on the den
- Time
- Ground cover: ground vegetation, smaller rocks, boulders
- Direction of approach: uphill, downhill, even terrain

3.3 Data analysis

Prior to statistical analyses in RStudio for Windows, we used ArcMap 10.2 to calculate the following parameters for our sample points: distance to the closest hiking trail, type of the closest hiking trail categorized by the number of hikers per year, distance to the hut, land use, type of park zone, elevation, aspect and slope. Collinearity check has shown that start distance (SD) and first reaction distance (FR) (correlation coefficient = 0.8), FR and FID (correlation coefficient = 0.9) and SD and FID (correlation coefficient = 0.7) are collinear. Collinear predictors could not be included in the same model, and we defined final model structure accordingly. We decided to fit a generalized additive model (*gam*) because of the non-linearity of the relationship between independent and dependent variables. A *gam* is a generalized linear model with the extension that allows the explanatory variables in the model to be defined by smoothed functions (EVERITT, 2005). After running preliminary models, FID was log-transformed to meet the assumption of the normality of residuals required by generalized additive models with Gaussian distribution of errors. An alpha = 0.05 has been set as significant threshold. The function `gam.check` was used to verify that we met the assumptions of the model. Our model structure was:

```
model1 = gam(log(FID) ~ newstart + date + s(time) + s(trail_distance,
by = frequency) + s(den_distance) + den_position + slope + land_use +
ground_cover + parkzones + s(elevation) + s(distance_hut) +
factor(age), data = db)
```

We included den distance and den position in our model because former studies found that distance to refuge (= den distance) and den position influence FID of a wide range of different taxa (e.g. COOPER & FREDERICK, 2007; DILL & HOUTMAN, 1989; KRAMER & BONENFANT, 1997; MARTÍN et al., 2004). Time and date were included because of differences within day and season (PETELLE et al., 2013). Another potential factor influencing FID of alpine marmots is the age categorized by young and adult (NEUHAUS & MANINI, 1998). Slope, land use, ground cover, type of park zone and elevation were included to see whether they have got an effect on FID. The most important potential factors influencing FID in our study are the distance to the closest hiking trail categorized by the number of hikers per year and the distance to the hut. Even if other studies found that start distance (SD) and first reaction distance (FR) affect FID (e.g. BLUMSTEIN, 2010; DUMONT et al., 2012) we could not include SD and FR to our model because of the collinearity. For taking into account these confounding factors, however, we created the variable “newstart” with the two categories “natural” (SD > FR > FID) and “broken” (SD = FR = FID) (see discussion **5.3**).

4 Results

We conducted 138 FID experiments on randomly chosen individuals from September the 2, through September 10th 2014 and 204 FID experiments from June 11th, through June 19th 2015 (see **Fig. 4**). Approaches happened between 7.30 am and 6.30 pm in September 2014 and 8.30 am and 6.45 pm in June 2015. Marmots were present at elevations from 2200 (tree line) to 3000 m, but they appeared to be most abundant at 2550 to 2700 m.

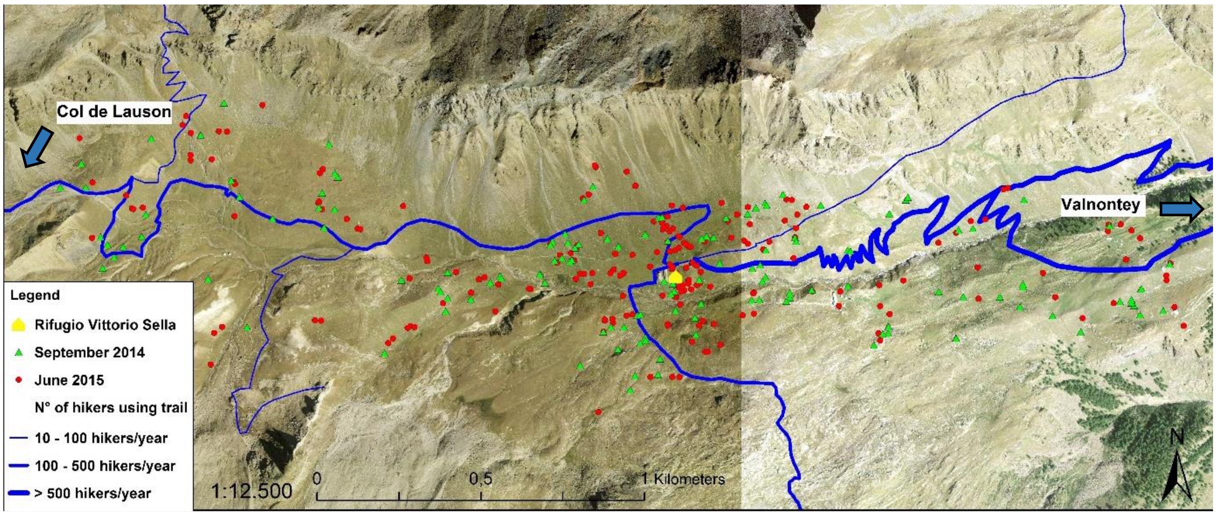

Fig. 4: Distribution of all sample points. Valnontey is the village where most tourists start their hike to Rifugio Vittorio Sella (2588 m) (yellow hut symbol). Col de Lauson (3314 m) is the only way to the closest valley (Valsavarenche), from where other tourists can come to the study area. Green triangles (September 2014) and red points (June 2015) indicate sample points. Different blue line widths indicate the different types of hiking trails, the thicker the line, the more people are using the trail.

We collected data from 117 FID experiments, where the den was behind the marmot seen from our position, 19 experiments where the den was between us and the marmot, 80 experiments where the den was on the side and 104 experiments where the marmot was sitting on the den. Most of our approaches (72%) happened in areas with grassland. Sixty per cent of the experiments were carried out in zones where grazing and some rural activities are admitted (B1 and B2). We performed 319 FID experiments on adult and 23 on young individuals. Most marmots were observed on south/ south-east slopes. Fifty seven per cent of the closest hiking trail fall into the category “100 to 500 hikers per year”.

Results show that start distance (SD), first reaction distance (FR) and flight initiation distance (FID) are strongly positively correlated (see **Fig. 5**) and that sample points where SD = FR = FID are randomly distributed all over the study area. There is no spatial pattern close respectively far away from the hiking trails (see **Fig. 6**).

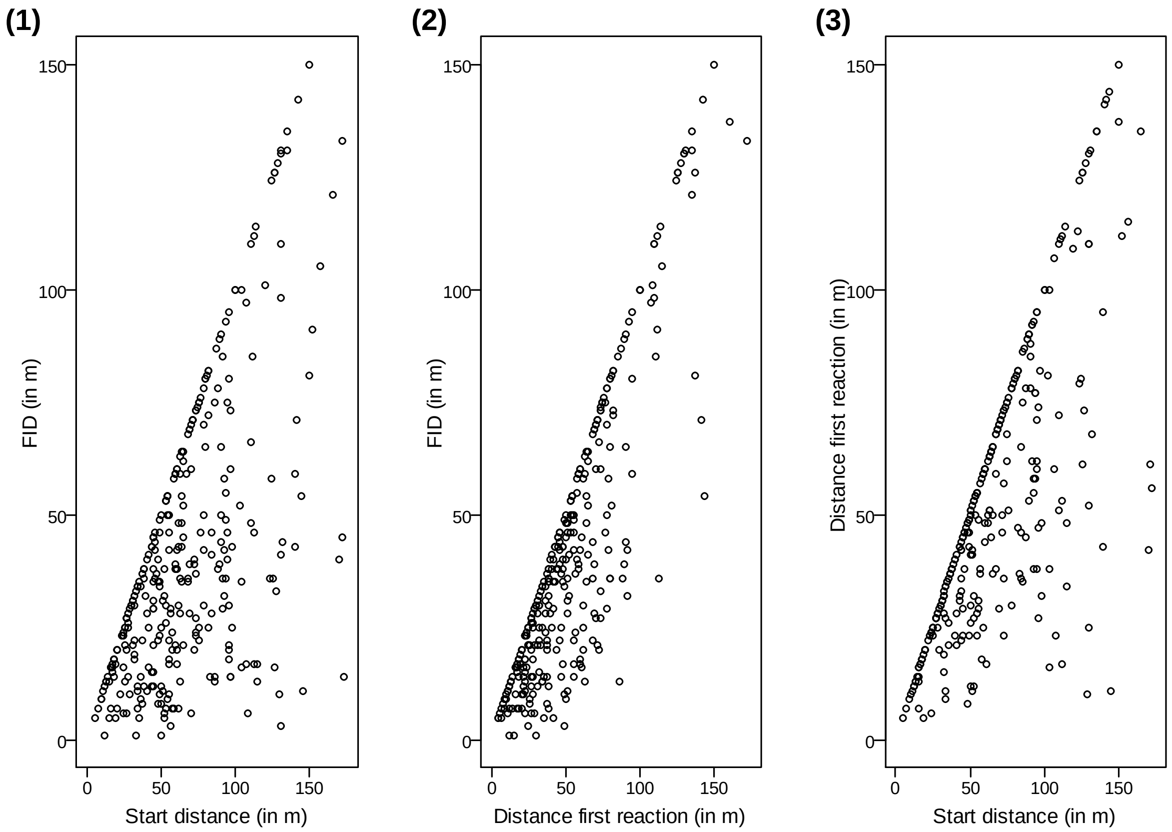

Fig. 5: Relationship between **(1)** starting distance (SD) and flight initiation distance (FID), **(2)** first reaction distance (FR) and FID and **(3)** SD and FID.

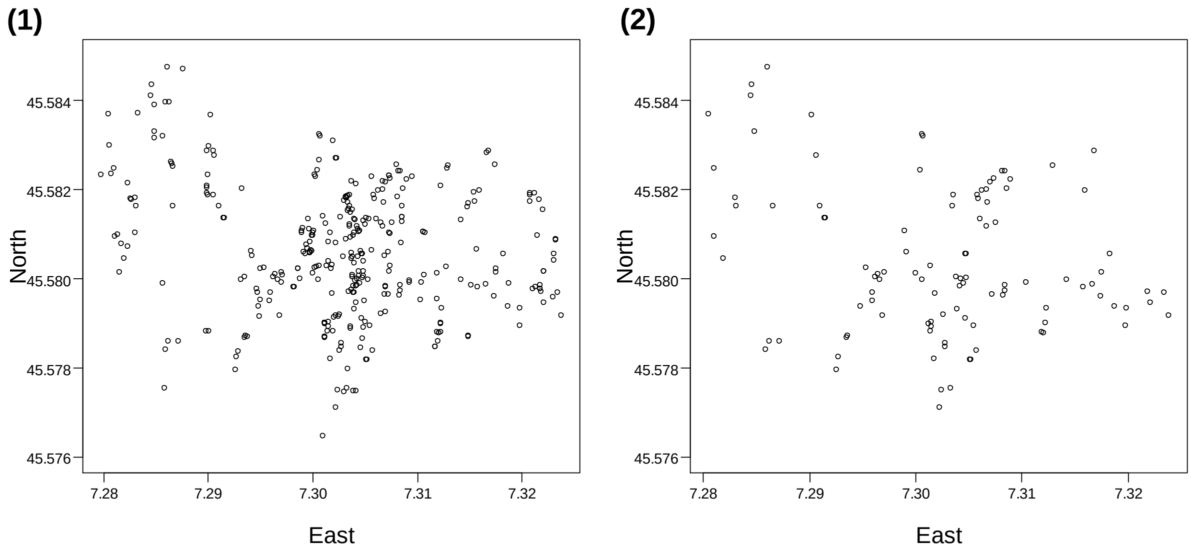

Fig. 6: Plot **(1)** displays the distribution of all sample points of September 2014 and June 2015 in our study are. Plot **(2)** displays all sample points where SD = FR = FID, thus experiments where marmots saw us and immediately fled.

Results from our generalized additive model are reported in **Table 1** and **Table 2**. The model explains 48% of the deviance. In **Fig. 7** it can be seen that FID was in general lower, the closer a marmot was situated to a hiking trail (red areas). Differences in the FID were very large, ranging from 1 m at less than 1 m from the trail to over 249 m for individuals with a distance of 237 m to the closest trail. We did not find a difference between FID recorded in September 2014 ($p = 0.102$) and June 2015 (see **Fig. 8** and **Table 1**).

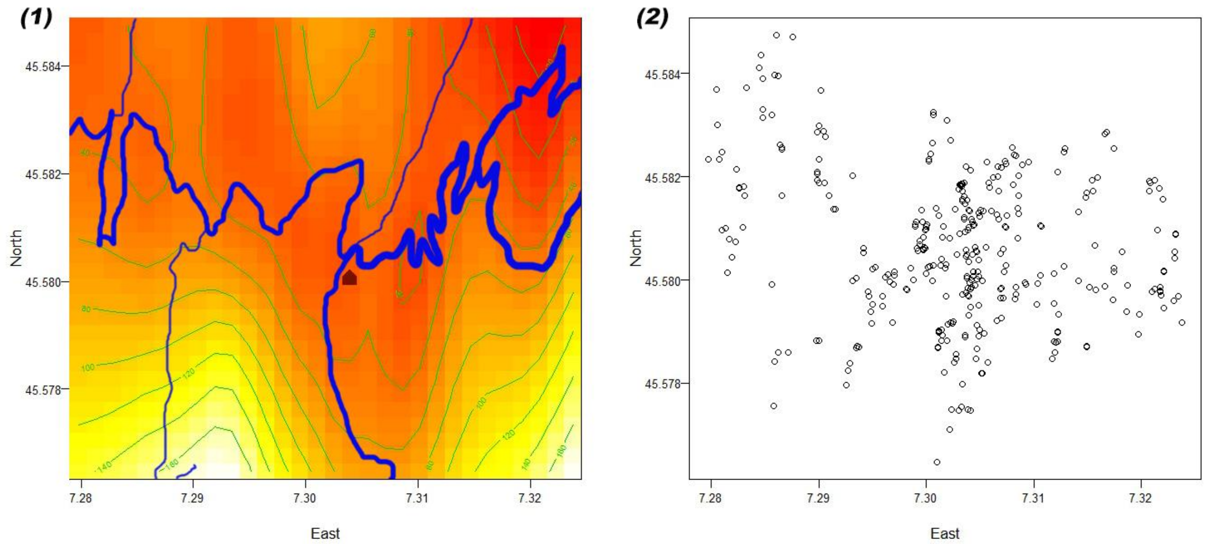

Fig. 7: Plot **(1)** displays the distribution of the FID of alpine marmots in our study area. The blue lines indicate hiking trails. The thicker the line, the more hikers are using the trail (categories: 10 – 100 hikers/year, 100 – 500 hikers/year and > 500 hikers/year). The brown house symbol indicates the hut Refugio Vittorio Sella. Red coloured areas represent a low FID whereas yellow/white areas represent a higher FID. Plot **(2)** displays the distribution of all sample points in our study area for depicting where we collected data.

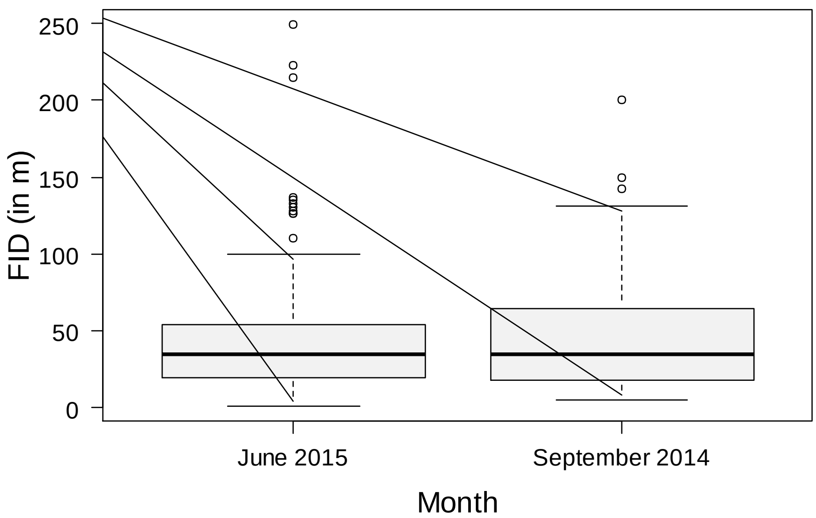

Fig. 8: Boxplot showing the FID of 342 alpine marmots as recorded in the Lauson area depending on the month of the data collection. The difference between FID of September 2014 (n = 138) and June 2015 (n = 204) was not statistically significant (generalized additive model, **Table 1**).

Ground cover, elevation, land use and type of park zone do not affect the FID of alpine marmots ($p > 0.05$). There were tendencies for FID to be influenced by the direction of approach (if we approached the animal from top of a hill or in even terrain ($p = 0.065$, $n = 219$)), and by the distance to the hut ($p = 0.077$) (see **Table 1** and **Table 2**).

Table 1: Generalized additive model fit to assess the effect of different categorial variables on the FID of alpine marmots (fixed factors). In parentheses, the variable of reference for categorial effects. Variables with statistically significant effects are identified by either one (*) ($p < 0.05$), two (**) ($p < 0.01$) or three asterisks (***) ($p < 0.001$), depending on the height of the significance. The reference categories are: newstart (broken), month (June 2015), den position (behind), slope (going_uphill), landuse (bush), gound cover (boulders), park zone (A1), age (adult).

	Estimates	Std. error	t-value	p-value
FID ~ categorial variable				
Intercept	3.2936	0.8046	4.094	6.43e-05 ***
Newstart (natural)	-0.2961	0.1288	-2.299	0.02266 *
Month (September 2014)	-0.2178	0.1323	-1.646	0.10156
Den position (between)	0.7572	0.2337	3.240	0.00143 **
Den position (on the den)	0.0137	0.1713	0.080	0.93636
Den position (side)	0.3855	0.1545	2.495	0.01349 *
Slope (other)	-0.2205	0.1188	-1.856	0.06513
Landuse (grasslands)	0.6394	0.7710	0.829	0.40803
Landuse (meadows)	0.5414	0.7711	0.702	0.48354
Landuse (screes)	0.5277	0.8569	0.616	0.53881
Ground cover (gound vegetation)	-0.2118	0.2215	-0.956	0.34025
Ground cover (rocks)	-0.1703	0.1953	-0.872	0.38455
Park zone (B1)	-0.3184	0.2566	-1.241	0.21642
Park zone (B2)	-0.0869	0.2744	-0.317	0.75185
Age (juvenile)	-0.5665	0.2042	-2.774	0.00612 **

Table 2: Generalized additive model fit to assess the effect of different smoothed terms and interactions on the FID of alpine marmots. Variables with statistically significant effects are identified by either one (*) ($p < 0.05$) or two asterisks (**) ($p < 0.01$), depending on the height of the significance.

	F	p-value
FID ~ smooth terms		
s(time)	2.111	0.03652 *
s(trail distance): 10 – 100 hikers/year	4.349	0.00174 **
s(trail distance): 100 – 500 hikers/year	3.844	0.05144
s(trail distance): > 500 hikers/year	5.863	0.01644 *
s(den distance)	0.461	0.64422
s(elevation)	1.027	0.39462
s(hut distance)	3.166	0.07684

Results show that FID of alpine marmots in the Lauson area is significantly lower at midday ($p = 0.037$) (see **Fig. 9 (1)** and **Table 2**). Furthermore there is a general trend for FID being lower close to the hut. The further away from the trail and the hut, the higher the FID (see **Fig. 9 (2)** and **Table 2**).

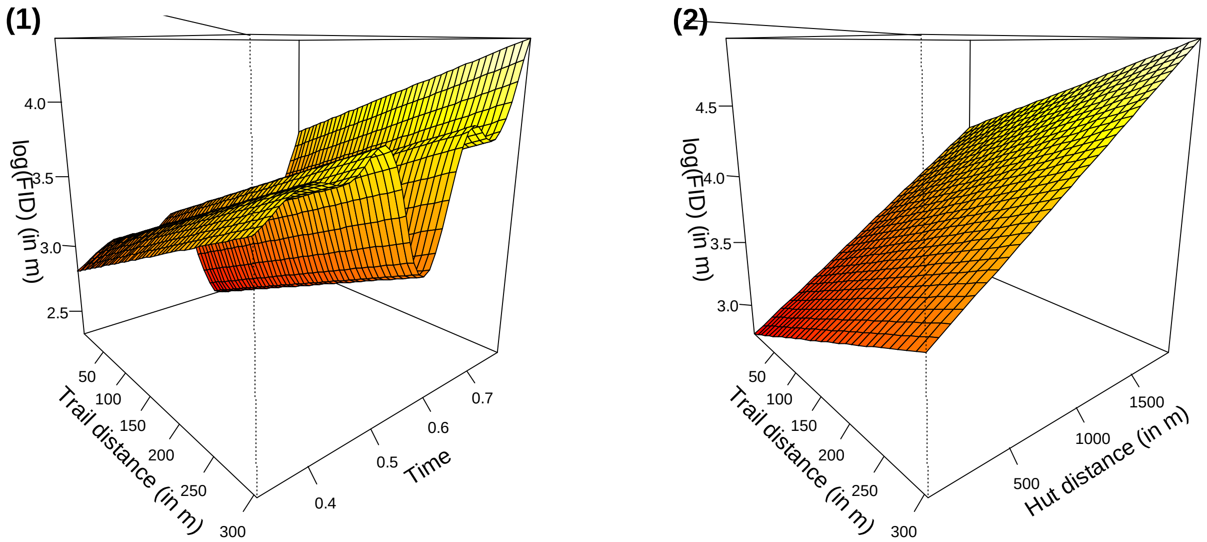

Fig. 9: Plot **(1)** showing the FID of 342 alpine marmots as recorded in the Lauson area depending on the distance to the closest hiking trail and the time, as predicted by the generalized additive model. The time of the day has been converted into a continuous variable ranging from 0 to 1. 0 indicates midnight and 1 indicates midnight 24 h later. 0.5 thus is 12 am. A value of 2 on the log(FID) axis indicates a FID of 7.3 m. Log(FID) = 4 indicates a FID of 54.6 m and log(FID) = 6 indicates a FID of 403.4 m. Plot **(2)** showing the FID of 342 alpine marmots as recorded in the Lauson area depending on the distance to the closest hiking trail and the distance to the hut Rifugio Vittorio Sella, as predicted by the generalized additive model. For a version of these plots with standard error, see appendix **Fig. A1** and **Fig. A2**.

There is a significant difference in FID of young ($p = 0.006$, $n = 23$) and adult individuals. FID of young individuals was significantly lower than FID of adult individuals (see **Fig. 10 (1)** and **Table 1**). In addition FID was significantly higher if the den was between the observer and the marmot ($p = 0.001$, $n = 19$) or on the side ($p = 0.014$, $n = 80$) instead of behind the marmot and the observer or if the marmot was sitting next to the den. There is no significant difference in FID between "side" and "between" (see **Fig. 10 (2)** and **Table 1**). For natural experiments (SD > FR > FID), FID is significantly lower than for experiments where the marmot saw us and immediately fled (SD = FR = FID) ($p = 0.023$, $n = 224$) (see **Table 1**).

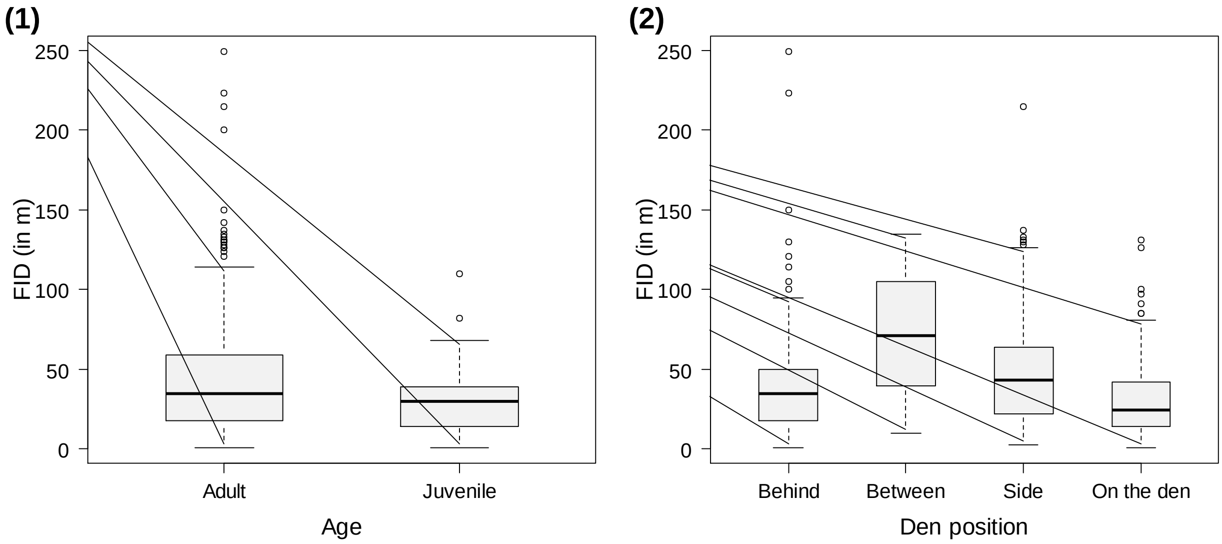

Fig. 10: Boxplot **(1)** showing the FID of 342 alpine marmots as recorded in the Lauson area in September 2014 and June 2015 depending on the age class of the individual. The mean FID of young individual is lower (mean = 33.43 m ± 14 m, n = 23) than the mean FID of adults (mean = 44.57 m ± 18 m, n = 319). Boxplot **(2)** showing the FID of 342 alpine marmots as recorded in the Lauson area in September 2014 and June 2015 depending on the position of the den. If the marmot sat on the den or if the den was behind the individual, the marmot flet later.

Results show a highly significant relationship between FID and the distance to the closest hiking trail categorized by the number of hikers per year (see **Fig. 11** and **Table 2**). With increasing distance to less frequented trails (10 – 100 hikers/year) FID increases much faster than for higher frequented trails (100 – 500 hikers/year and > 500 hikers/year). Results do not show a difference between FID in relation to the distance to trails with 100 – 500 hikers/year and > 500 hikers/year.

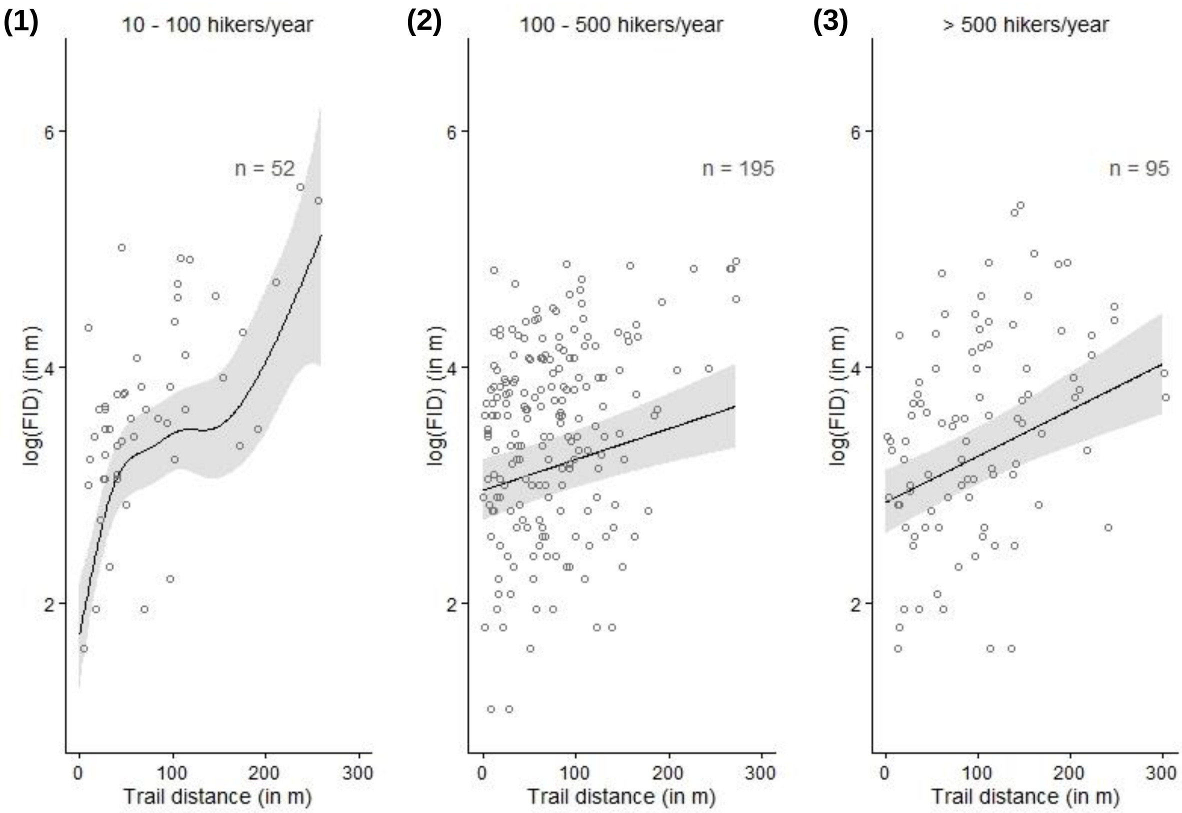

Fig. 11: Plots showing the effect of the distance to trail on FID of alpine marmots for different types of hiking trails (**(1)** 10 – 100 hikers/year, **(2)** 100 – 500 hikers/year, **(3)** > 500 hikers/year) as predicted by the generalized additive model. In the scenario hut distance, den distance and elevation have been kept to median. Time was set to morning, month to June, age to adult, den position to behind, land use to grasslands, ground cover to small rocks, new start to natural, park zone to B2 and slope to other.

5 Discussion

We found that alpine marmots close to high frequented trails are habituated because they flee significantly later than individuals in remote areas. We did not find seasonal differences in the habituation level of those marmots. If the den was on the side or between the observer and the marmots FID was significantly lower. Furthermore FID was lower at midday and for experiments where SD > FR > FID. Young individuals fled significantly later than adults. There were tendencies for FID to be influenced by the distance to the hut. Elevation, land use, ground cover, type of park zone, slope and the den distance did not affect the flight behaviour of alpine marmots in the Gran Paradiso National Park and therefore are not part of the discussion.

The main objective of this study was to test habituation of alpine marmots in the Gran Paradiso National Park (Italy) by analysing flight initiation distances (FID) in relation to the distances to the closest hiking trail categorized by the number of hikers per year. We used FID because it "*is an easily measured quantitative indicator*" (LIN et al., 2012, p. 31) of an animals response to human disturbance. We found that FID is lower close to high frequented trails compared to remote areas with almost no tourist traffic because individuals close to trails are habituated. LI et al. (2011) already found that marmots habituate to human disturbance during the summer season but they did not include the distance to the closest trail to their analyses. MAININI et al. (1993) tested the behaviour of alpine marmots under the influence of different hiking activities and found that marmots show the strongest reaction in the case of a hiker with a free-running dog. But they did as well not include the distance to the trail to their analyses. BONENFANT & KRAMER (1997) analysed the influence of the distance to the burrow on the FID in woodchucks (*Marmota monax*). We included the den position, the distance to the den and the distance to the closest trail to our analyses to see the effect of those variables on the FID. The distance to the trail is an important variable to show that animals far from trails show a stronger response to human disturbance compared to individuals living close to trails. Based on our results the **distance to the closest hiking trail is the main driver of habituation**.

5.1 Spatial and temporal habituation in alpine marmots

We found that individuals that are situated close to high frequented hiking trails flee significantly later than those in remote areas thus further away from the trail (see **Fig. 11**). Hence alpine marmots living close to high frequented hiking trails in the Gran Paradiso National Park are able to adapt to human presence and therefore are habituated. The habituation effect of marmots living close to high frequented trails (> 100 hikers/year) is higher than the one of marmots living close to less frequented trails (> 100 hikers per year). For less frequented trails the habituation effect decreases faster with increasing distance to the trail than for high frequented trails. The highly significant relationship between FID and trail distance categorized by the number of hikers per year (see **Table 2**) confirms our hypothesis and the result by LI et al. (2011) that alpine marmots are habituated. However, for the first time we disentangled the development of the habituation behaviour by relating it with the distance to the closest hiking trail and thus where humans are more likely to occur. Human footprints are responsible for habitat loss, and the habituation behaviour is one of the possible responses undertaken by animals to keep using those areas.

Nevertheless we have to take into account that different life stages and age classes may react differently to human disturbance. It is possible that some individuals seem to habituate or be unaffected whereas other individuals are affected negatively by disturbances (GRIFFIN et al., 2007). MÜLLNER et al. (2004) found that juvenile hoatzins (*Opisthocomus hoatzin*) that are exposed to regular tourism are affected more negatively (reduced body mass, increased hormonal stress response, lower survival) than those at undisturbed sites. Adult hoatzins however seem to habituate. Hence it would be good not only taking into account the FID and distance to trail but also the individual fitness level and age class of each tested animal to test habituation.

Results of our generalized additive model do not show a significant difference between FID values of September 2014 and June 2015 (see **Fig. 8**). According to our hypotheses this leads to the assumption that alpine marmots are always habituated and that habituation is retained during hibernation. There is no seasonal variation in the habituation behaviour of alpine marmots in early and late summer. NEUHAUS & MANINI (1998) could as well not identify significant differences in the FID of adult marmots in early and late summer season in either low frequented or high frequented areas. These results confirm the study by CLEMENS et al. (2009) in which they found that memory is retained during hibernation in alpine marmots.

5.2 Effect of den position, time and age on FID

The analysis of our data shows that FID is influenced by the position of the den (see **Fig. 10 (2)**). KRAMER & BONENFANTS (1997) result that FID is lower, if the den is between the observer and the marmot or on the side could be confirmed because in these cases the individual has to run towards the observer to reach its refuge. Whereas FID is higher if the den is behind the marmot and the highest if the individual is sitting on the den because it feels save from predators close to its refuge. Alpine marmots thus take into account the direction of approach of the observer respectively the predator.

ARMITAGE (1962) could identify a peak of activity in the morning and in the afternoon in yellow-bellied marmots. Our results show that FID of alpine marmots is reduced at midday, means they seem to be less sensitive to disturbance and thus flee later (see **Fig. 9 (1)**). Regarding both results one conclusion could be that they feed and are more vigilant during the morning and in the afternoon. At midday alpine marmots seem to be less active and therefore are less vigilant. And less vigilance and activity could be the reasons for lower FID. Another explanation could be the opposite: at midday marmots do not feed and are laying down outside their dens waiting for cooler temperatures. At the same time they can spend all the time being vigilant and, e.g., watching an approaching observer for a longer time before fleeing which leads to lower FID. Another explanation could be that the activity of red foxes is very low at midday. Apart from these explanations it would be interesting to study why the attention level of alpine marmots is reduced at midday.

Our research has shown that FID of young alpine marmots is significantly lower than FID of adults (see **Fig. 10 (1)**). Young individuals therefore seem to be more curious and maybe unexperienced as well. However it has to mentioned that 319 adult marmots and only 23 young marmots were observed in the study. Due to the fact that it is diffucult to distinguish unmarked young and adult alpine marmots in the field we cannot assure that no juveniles were counted as adults. NEUHAUS & MANINI (1998) who tested, amongst other things, the effect of age on the FID of alpine marmots in the Bernese Oberland in Switzerland found as well that flight distances are much shorter in young than in adult individuals. In further studies it would nevertheless be interesting to examine more precicely the effect of age on FID of marked alpine marmots in the Gran Paradiso National Park.

5.3 Relationship between SD, FR and FID

Many papers that deal with FID experiments take into account the starting distance and the first reaction distance of the animals because previous research has demonstrated that they affect FID (BLUMSTEIN, 2010; DILL & HOUTMAN, 1989; DUMONT et al., 2012; PETELLE et al., 2013) . DUMONT et al. (2012) found that there is a correlation between start distance (SD), first reaction distance (FR) and FID. This result can be confirmed (see **Fig. 5**). Due to the fact that SD and FR and FID (correlation coefficient > 0.7) are positively correlated we did not include SD and FR in our model. The problem with our dataset, however, is that we cut the data when

SD = FR = FID (= marmot saw us and immediately fled), thus we underestimated the FID. **Fig. 6** shows that experiments where we cut the data (SD = FR = FID) are randomly distributed, thus there is no spatial pattern close respectively far from the hiking trails. If we now assume that it is more likely to conduct an experiment where SD = FR = FID for non-habituated individuals because those individuals are alert to disturbances in a larger radius (i.e. = they have a greater area of influence) than habituated animals, we come to the conclusion that we underestimated the FID of non-habituated individuals, hence we overestimated the habituation effect of non-habituated marmots all over our study area. To take into account this bias we included the variable “newstart” as a confounding factor to our model. For natural experiments (SD > FR > FID) FID is significantly lower than for broken experiments (SD = FR = FID). It can thus be seen that even if we take into account that we underestimated FID of non-habituated animals, our results still show a significant difference in the FID close and far from low and high frequented hiking trails.

5.4 Management implications

These outcomes show that marmots can develop their habituation behaviour and deal with humans as long as hikers stay on the trails (= predictable behaviour). NEUHAUS & MANINI (1998), MAGLE et al. (2005) and LOUIS & LE BERRE (2000) already found that alpine marmots and pairie dogs (*Cynomys ludovicianus*) show reduced FID if human activities are foreseeable. Leaving the trail, however, is an unpredictable activity for marmots and thus alters their behaviour. But even if new trails are created animals would probably habituate after a while. For maintaining the variability of behaviour in a population it is nevertheless advisable to direct the flow of visitors to a network of a few well-maintained trails instead of cutting remote areas. Having only habituated marmots could eventually lead to the situation that individuals start not reacting properly to natural predators. It should thus be avoided to create too many new trails.

Nevertheless it is important that wild animals are perceptible for tourists. Especially in National Parks where most people come to for seeing wild animals in their natural habitat. For example for many tourists coming to the Gran Paradiso National Park watching ibex in their natural environment is the reason for their visit. This, in turn, is essential for the income for many local people and the park itself. It is thus important to find a good balance between making wildlife perceptible for visitors and preserve refuges for animals.

6 Conclusion

Coming back to the beginning, high tourist numbers in alpine regions and the related technical development of remote areas lead to disturbances of the alpine fauna and habitat loss. Especially hibernating animals such as alpine marmots are particularly affected by human disturbances because they need to build up sufficient reserves of body fat during the short summer season. Fleeing to often thus means loosing time and energy and results in a reduced fitness level. To avoid this and in order to keep using those areas, some animals are able to adapt to human presence (MILLER et al., 2011). Habituation hence is a good response by animals of not wasting time and energy in order to survive.

All in all we come to the conclusion that alpine marmots in the Gran Paradiso National Park habituate to predictable human disturbance by showing reduced flight distances close to high frequented trails, but react more sensitive to unpredictable activities such as walking off-trail which leads to unnecessary energy loss and consequently to decreased fitness and reduced reproduction rates. They do take into account the position of the den when considering their flight behaviour and flee later when they are young and at midday. The season does not affect the FID of alpine marmots, thus the level of habituation is comparable prior (September 2014) and after (June 2015) hibernation. Due to our results the distance to the closest hiking trail is the main driver of habituation.

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Appendix

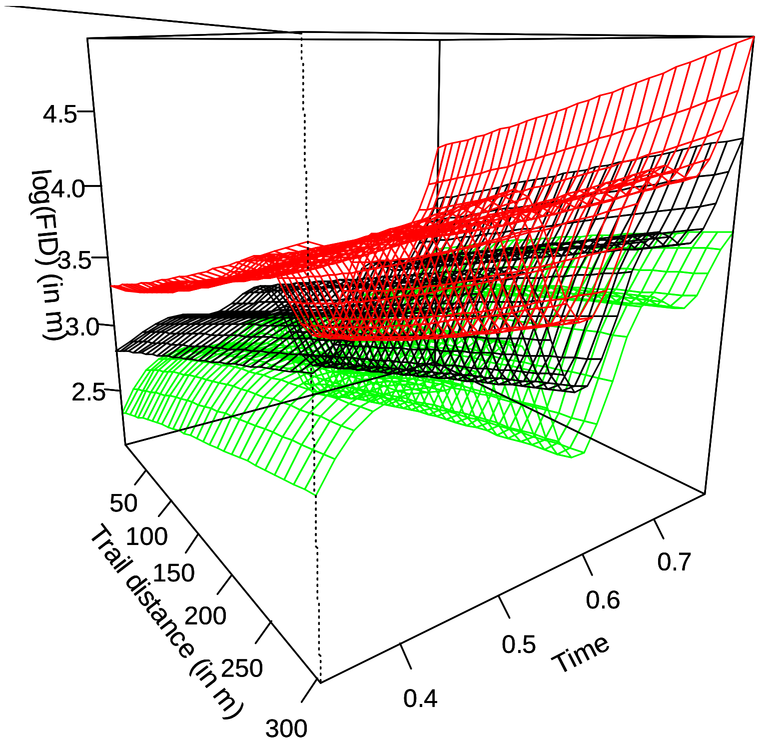

Fig. A1: Plot showing the FID of 342 alpine marmots as recorded in the Lauson area depending on the distance to the closest hiking trail and the time. Red and green indicate +/- 1 standard error.

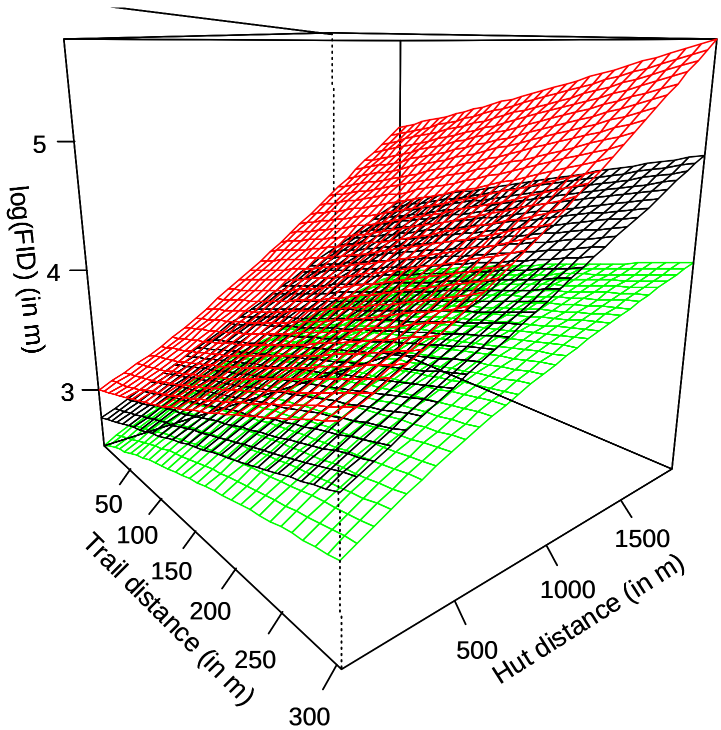

Fig. A2: Plot showing the FID of 342 alpine marmots as recorded in the Lauson area depending on the distance to the closest hiking trail and the distance to the hut Rifugio Vittorio Sella. Red and green indicate +/- 1 standard error.