



Elevation shapes predation pressure: Evidence from artificial caterpillars in the Italian Alps

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Abstract. This study investigated predation pressure along an altitudinal gradient in the Eastern Alps using the sentinel prey method with artificial caterpillars made of green and brown plasticine. The aim was to assess how elevation affects the intensity and composition of predation, distinguishing between invertebrate and vertebrate attacks. A total of 750 models were placed at different elevations between 1300 and 2100 m a.s.l., exposed for 24 h, and then examined for characteristic attack marks. Results showed that, despite lacking natural cues such as odour, movement, and chemical signals, the artificial caterpillars were frequently attacked, confirming the validity of the method. Predation pressure significantly decreased with increasing elevation, with the lowest attack rate recorded at 2100 m and no bird attacks observed at this elevation. Invertebrates were the dominant predator group, while bird attacks were comparatively rare. No significant colour effect was detected. Overall, the findings align with previous literature, supporting the hypothesis that predation decreases at higher elevations, likely due to lower predator densities and harsher environmental conditions.

1. INTRODUCTION

Predation represents one of the fundamental ecological processes regulating the structure, composition, and dynamics of biological communities. Predator-prey interactions are key drivers of community structure and ecosystem functioning, influencing species' spatial distribution, population dynamics, and evolutionary trajectories. The presence of predators can exert both direct effects, such as the numerical reduction of prey populations, and indirect ones, through behavioural or morphological changes in prey species (Peacor & Werner, 2001; Andrén & Liberg, 2024). For instance, experimental studies on aphid-predator systems have shown that predator presence regulates not only aphid population abundance but also the primary productivity of ecosystems, highlighting the stabilising role of predation within trophic networks (Curtsdotter et al., 2019). These mechanisms profoundly affect biodiversity and trophic network stability, making predation a key component in understanding the functioning of ecosystems.

Studying predation on insect prey is therefore essential for understanding how biological communities respond to environmental and anthropogenic change, as variation in predation pressure on insects can indicate alterations in habitat availability, faunal composition, or climate (Hargreaves, 2024). In the context of rapid global change, examining how predation varies along environmental gradients, such as those of altitude, latitude, or urbanisation, is crucial

for predicting the effects of climate warming or habitat alterations on ecological interactions. Globally, predation on insect prey tends to increase towards the equator and at lower elevations (Roslin et al., 2017), whereas in mountain environments it generally decreases with altitude, likely due to lower predator density and activity (Camacho & Avilés, 2019). Anthropogenic factors, such as urbanisation and human density, also significantly influence the structure of trophic networks and the intensity of predation (Hernández-Agüero et al., 2024), although recent evidence suggests that some macroecological patterns, such as latitudinal gradients in predation, may persist even in urban contexts (Hargreaves et al., 2024). Research on predation thus not only advances the theoretical understanding of trophic dynamics, but also provides information relevant for biodiversity conservation and sustainable ecosystem management.

In this context, altitude provides a natural gradient ideal for investigating how environmental factors shape trophic interactions. Variation in temperature, vegetation structure, and faunal composition observed along mountain slopes strongly affects predator distribution and activity, with potentially relevant consequences for predation pressure (Roslin et al., 2017; Camacho & Avilés, 2019). However, empirical evidence remains scarce, particularly in European mountain ecosystems, where comparative and standardised experimental approaches could help clarify the

mechanisms regulating predation in high-elevation environments (Lövei & Ferrante, 2017).

Predation risk is notoriously difficult to assess across different ecosystems. Over the past two decades, numerous studies have examined predation pressure using artificial caterpillar models, contributing to a better understanding of how predator-prey interactions vary along environmental gradients. Roslin et al. (2017) demonstrated, on a global scale, that the risk of predation for insect prey increases at both lower latitudes and lower elevations, suggesting that ambient temperature and primary productivity may strongly modulate predator activity. Seifert et al. (2015) found that, in tropical environments, predation was more intense in agricultural or semi-natural landscapes than in primary forest, while Seifert et al. (2016) showed that daytime and nighttime predation can differ significantly in tropical systems, highlighting the importance of predator behaviour and activity patterns. Subsequent studies, such as that of Valdés-Correcher et al. (2022), improved the reproducibility and accuracy of the sentinel prey method, i.e. the deployment of standardised prey items in the field to quantify predator attacks, confirming its validity for identifying the main groups of predators (birds, mammals, and invertebrates) across different ecosystems. More recently, Baker (2025) applied the same technique to assess predation on *Danaus plexippus* larvae, demonstrating that artificial prey models can effectively be used to test ecological hypotheses, including in conservation contexts.

The sentinel prey technique has become a widely adopted experimental approach for quantifying predation pressure across natural environments. By deploying standardised baits, either real or artificial, that serve as “sentinel” prey, researchers can obtain comparable estimates of attack rates among habitats or ecological conditions (Howe et al., 2009). Plasticine caterpillars are easy to standardise and manipulate, allow for attaining large sample sizes at low cost, and are therefore particularly suitable for comparative studies and hypothesis testing, providing high repeatability and statistical power (Lövei & Ferrante, 2017; Rössler et al., 2018; Valdés-Correcher et al., 2022). However, artificial prey lacks olfactory and behavioural cues and cannot mimic key biological traits of real larvae, such as movement or chemical signals, which may reduce encounter rates with some predator groups and lead to a conservative estimate of true predation pressure (Howe et al., 2009; Low et al., 2014; Sam et al., 2015; Lövei & Ferrante, 2017). An alternative to artificial prey is the use of freshly killed real larvae, which may increase ecological realism but might conflate scavenging activity with true predation, thus reducing the interpretability of predation patterns (Nagy et al., 2020). Overall, dummy prey items represent a robust and widely used option for quantifying predation risk along environmental gradients, as they provide a level of standardisation and comparability that alternative approaches cannot guarantee. These properties are particularly relevant in mountain systems, where steep environmental gradients, marked microclimatic variation over short distances, and limited accessibility demand

methods capable of isolating ecological signals from methodological variability. Their successful application in remote high-mountain settings (Roslin et al., 2017) further supports their suitability for assessing broad-scale patterns of predation pressure.

In this study, we tested three main hypotheses concerning the variation of predation pressure along an Alpine altitudinal gradient. (H1) Predation pressure was hypothesised to decrease with increasing altitude, being higher at lower sites. (H2) Invertebrates were expected to cause a greater number of attacks than birds. Because artificial caterpillars were deployed on tree trunks and branches 1–2 m above ground, the experimental design was expected to preferentially expose models to predator guilds active on woody vegetation, particularly ants and other arboreal invertebrates. Birds foraging on trees represented another relevant predator group, whereas strictly ground-dwelling predators were less likely to encounter the clay models. Differences in attack rates between predator groups may therefore reflect differences in local abundance, activity, and probability of encountering the models. Moreover, mound-building wood ants are very abundant in the mountain conifer forests of the Alps where they are expected to play a major role as predators of other arthropods (Guariento et al., 2018). Finally, (H3) we hypothesised that the colour of the models (green or brown) might influence the probability of attack, depending on their degree of camouflage with the surrounding environment.

2. MATERIAL AND METHODS

2.1. Area of study

The study was conducted along an altitudinal gradient ranging from 1300 to 2100 m a.s.l. in the Montasilone/Tessellberg area (Val Pusteria, Province of Bolzano, South Tyrol, Italy). This Alpine region, part of the Natura 2000 network, is characterised by high environmental heterogeneity, comprising montane to sub-alpine spruce and larch forests interspersed with clearings and high-elevation pastures. Such a mosaic landscape characterises much of the study area and may influence local predator activity and habitat structure along the gradient. However, experimental sites were selected to maintain broadly comparable forest conditions across elevations.

Five experimental sites were established at 1300 (46°48'36.17 N, 11°58'16.00 E), 1500 (46°49'42.61 N, 11°59'17.72 E), 1700 (46°49'58.64 N, 12°00'02.74 E), 1900 (46°50'14.41 N, 12°00'48.48 E), and 2100 (46°50'14.41 N, 12°01'13.23 E) m a.s.l. along a south-facing slope selected to ensure broadly comparable exposure and vegetation conditions (Fig. 1). Forest composition and structure changed progressively along the elevational gradient. The 1300 m site was located in a predominantly Norway spruce (*Picea abies*) forest directly adjacent to a road and approximately 1 km from a relatively large cluster of hotels. At 1500 m, the forest remained largely dominated by Norway spruce, but the site was located away from the main road, near a church, a few scattered farmsteads, and an adjacent pasture. The intermediate sites at 1700 and 1900 m were not located close to substantial built infrastructure and represented a gradual transition from spruce-dominated forest stands towards more open sub-alpine forest. European larch (*Larix decidua*) occurred throughout the study area and contributed to forest structure across the elevational gradient. At 2100 m, the forest was dominated by

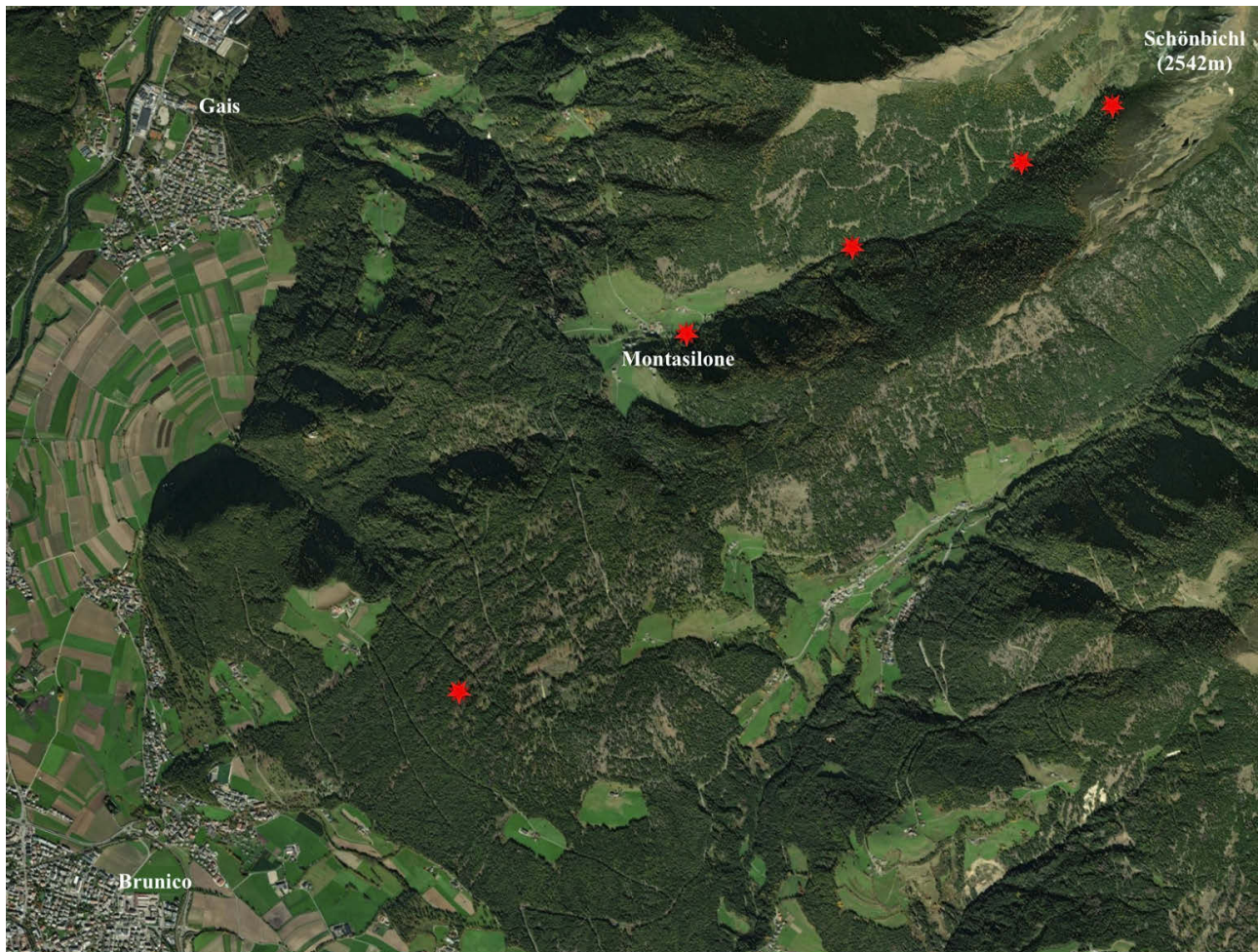


Fig. 1. GIS-based satellite map of the Montasilone/Tesselberg study area, Val Pusteria, South Tyrol, Italy, produced using an ESRI basemap layer. Red markers indicate the five experimental sites along the altitudinal gradient, ordered from left to right as 1300, 1500, 1700, 1900, and 2100 m a.s.l.

Swiss stone pine (*Pinus cembra*) and had a more open structure, with greater spacing between individual trees than at lower elevations (Fig. S1). This forest was surrounded by alpine cattle pasture but was fenced and physically separated from livestock grazing, thus representing a true forest stand rather than wooded pasture. The understory along the gradient included typical montane and subalpine species such as *Vaccinium myrtillus*, *Rhododendron ferrugineum*, and *Homogyne alpina*. The variation in microclimatic and structural conditions along this gradient offers a robust framework for examining changes in predator activity, in line with previous studies on altitudinal variation in predation (Seifert et al., 2016; Roslin et al., 2017; Valdés-Correcher et al., 2022).

2.2. Experimental design

To quantify predation pressure along the altitudinal gradient, we deployed artificial lepidopteran larvae made of non-toxic plasticine, a standardised method for comparing predator activity across ecological gradients (Howe et al., 2009; Lövei & Ferrante, 2017; Rößler et al., 2018; Valdés-Correcher et al., 2022).

The cylindrical models (“fake caterpillars”) were made of soft, non-toxic plasticine (Becks Plastilin, Germany) and measured approximately 30×5 mm. They were produced in two colour variants, green and brown (Figs 2 and 3), reflecting colouration found in many lepidopteran larvae in Central Europe. Background colour at the individual model locations was not quan-

titatively measured or scored. During each sampling session, 50 dummies were deployed at each of the five altitudinal sites (25 green and 25 brown per site), resulting in 250 models per session. The experiment was repeated three times between late May and late June 2025 (24 May, 10 June, and 20 June), yielding a total of 750 dummy deployments. Although no universally standardised sample size has been established for studies using artificial sentinel prey (Lövei & Ferrante, 2017), our design provided 50 models per elevation in each sampling session and 150 model deployments per elevation across the three temporal replicates. This cumulative sampling effort is comparable in magnitude to previous artificial-caterpillar studies; for example, Seifert et al. (2015) deployed 162 models per habitat. The replication across three sampling sessions further provided repeated estimates of predation pressure over the study period. Models were attached to the vegetation using entomological pins at a height of approximately 1–2 m above ground and spaced about 5 m apart, following recommendations of Hong et al. (2011) and Seifert et al. (2015). At all sites, suitable attachment points at this height were provided exclusively by tree structures (mainly spruce, larch, or pine). Consequently, artificial caterpillars were consistently attached to branches or directly to the trunks of trees, rather than to low shrubs or herbaceous vegetation, ensuring comparable exposure conditions across the gradient. Care was taken not to leave accidental marks on the plasticine during placement. Each exposure session lasted ~24 h, after which the models were collected



Fig. 2. Plasticine dummy caterpillar pinned onto a conifer branch to assess predation rates in the field.

and inspected. Each session represented an independent experiment, and every prey item was examined only once (Lövei & Ferrante, 2017). The models were transported in rigid containers and inspected prior to each deployment to check for non-biological marks or accidental damage.

2.3. Identification of predation marks

Attributing a given mark to a specific predator group (arthropods, birds, mammals, etc.) is often challenging and may remain contentious in some cases. We used the reference scheme sug-

gested by Valdés-Correcher et al. (2022). Accordingly, attack marks were classified based on the morphology of the lesions:

Single holes or puncture holes → typically indicative of bird attacks.

Irregular chewing marks → attributed to invertebrates, such as beetles or ants (Fig. 3).

Undefined marks or abrasions → not attributable with certainty to any predator group.

In our dataset, marks classified as “undefined” were interpreted as artefacts caused by abiotic factors rather than predation. These traces likely resulted from accidental contact with vegetation or minor deformation occurring during model placement or retrieval. Because they lacked the diagnostic morphology of predator attacks, they were not considered predation events and were treated as non-attacked models in the analyses. Because chewing marks produced by different arthropod taxa may overlap in morphology, we did not attempt a finer taxonomic attribution of individual lesions. Accordingly, attacks showing irregular chewing damage were conservatively classified as invertebrate attacks rather than assigned to specific predator groups within arthropods.

2.4. Statistical analyses

The binary response variable was the presence/absence of an attack, classified as bird or insect attacks. Explanatory variables included altitudinal level (treated as a categorical factor with five levels: 1300, 1500, 1700, 1900, and 2100 m a.s.l.) and prey colour. We fitted generalised linear models (GLMs) including altitudinal level, prey colour, and their interaction. When the interaction term was not significant, results of the main effects are presented. In addition, sampling session (three exposure rounds) was included in the model to test whether predation rates varied among the different sampling dates. Models were fitted with a binomial error distribution, followed by post-hoc tests to assess the effects of colour and altitude. Statistical significance was accepted at a Type I error rate of $p < 0.05$. Analyses were performed in Jamovi version 2.7.12 (The Jamovi Project, <https://www.ja->



Fig. 3. Predation marks on plasticine caterpillar models: Puncture marks from a bird attack (left) and chewing marks from invertebrates (right).

movi.org, 2025), using the modules GAMLj3 (version 3.6.5) and Rj (version 2.6.0). The Rj module is built upon the R statistical environment (version 4.5.1). Eta-squared values were reported as descriptive measures of effect size. Although this metric is more commonly used with normally distributed response variables, it is presented here as an approximate indicator of effect magnitude. For binary outcomes, eta-squared values should therefore be interpreted with caution.

3. RESULTS

Altogether 750 artificial prey models were deployed at the five altitudinal sites. Of these, 449 individuals remained unattacked (59.9%), while 283 were attacked (37.7%), and 18 were not recovered from the field (2.4%). Attacks were strongly biased towards invertebrates, which accounted for 241 cases (85.2% of all predation events; 32.1% of the total deployed models), whereas birds were responsible for only 42 attacks (14.8% of predation events; 5.6% of the total). Thus, invertebrate predation risk was more than five times higher than bird predation. Across the whole dataset, eleva-

tion emerged as the primary driver of variation in predation rates. The likelihood of attack decreased significantly with increasing altitude ($\chi^2 = 55.85$, $df = 4$, $p < 0.001$, $\eta^2 = 0.0562$; Fig. 4a). The steepest decline was observed above 1700 m. The highest overall attack rate was recorded at 1300 m, where 75 of 150 deployed models were attacked (50.0%), whereas 23 of 150 models were attacked at 2100 m (15.3%). Thus, the attack rate at the highest site was less than one third of that recorded at the lowest site. By contrast, prey colour did not influence the probability of attack ($\chi^2 = 0.861$, $p = 0.354$), and no significant interaction between elevation and colour was detected ($\chi^2 = 2.938$, $p = 0.568$). When considering only attacks attributed to invertebrates, the same altitudinal pattern was evident (Fig. 4b). Invertebrate predation decreased significantly with increasing elevation ($\chi^2 = 38.599$, $df = 4$, $p < 0.001$, $\eta^2 = 0.0410$). The effect was particularly marked between 1900 and 2100 m, where the number of attacks dropped sharply. As with total predation, no differences were found between green and brown prey ($\chi^2 = 0.657$, $p = 0.418$), and the elevation $\times$ colour interaction was not significant ($\chi^2 = 6.759$, $p = 0.149$). Field observations indicated that ants of the genus *Formica* were present at all study sites and represented the most conspicuous predatory invertebrates along the transect. At the highest site (2100 m), however, they were only rarely observed. Other predatory invertebrates, including Staphylinidae and Carabidae, were also observed, although much less frequently. Attacks by birds displayed a markedly different elevational pattern compared to invertebrates (Fig. 4c). Predation was concentrated at intermediate elevations (1500–1700 m), where the majority of bird attacks occurred, while no bird predation events were recorded at the highest site (2100 m). The effect of elevation was statistically significant ($\chi^2 = 11.94$, $df = 3$, $p = 0.008$, $\eta^2 = 0.0399$). Prey colour did not significantly influence bird attacks ($\chi^2 = 3.02$, $p = 0.082$), and the elevation $\times$ colour interaction was again not significant ($\chi^2 = 5.52$, $p = 0.138$). Sampling session did not significantly affect overall predation probability ($\chi^2 = 0.195$, $df = 2$, $p = 0.907$; Table S1).

4. DISCUSSION

4.1. Total predation and the role of altitude

The results of this study suggest a decrease in predation pressure along the examined altitudinal gradient, with a particularly marked decline above 1700 m up to the highest site (2100 m). Within the studied system, predation risk decreased towards higher elevations. This pattern supports the prediction of hypothesis H1 and is consistent with previous studies reporting lower predation intensity at higher elevations, mainly due to harsher climatic conditions, lower primary productivity, and reduced predator richness and activity at higher elevations (Roslin et al., 2017; Camacho & Avilés, 2019). These findings suggest that predator activity in alpine environments may be constrained by thermal conditions, resource availability, and the microclimatic characteristics of subalpine and alpine habitats.

Temporal variation in predation rates has been documented in other ecosystems, where predator activity and

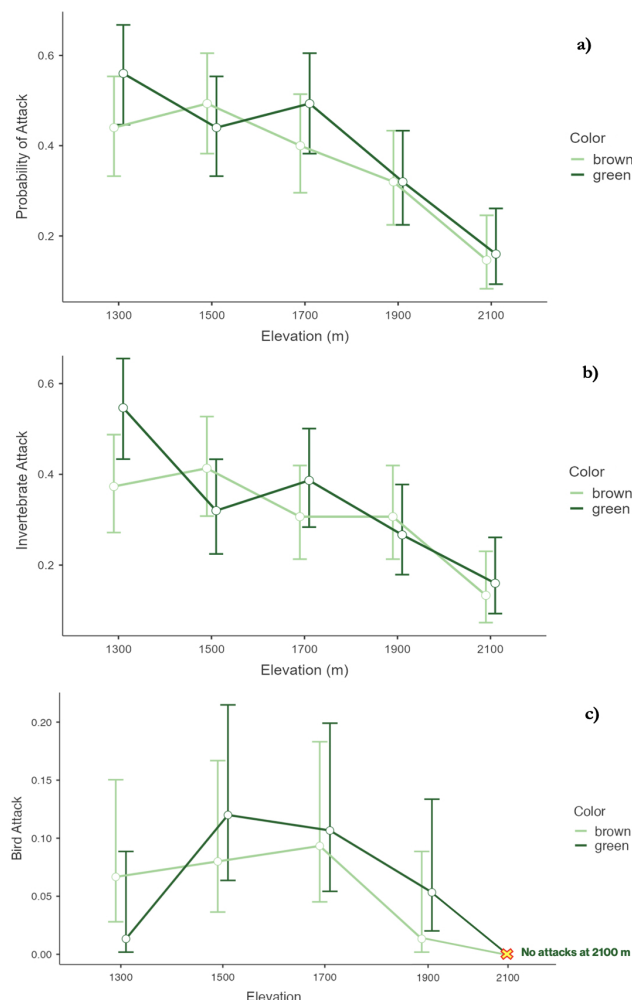


Fig. 4. Probability of attack on artificial prey across the altitudinal gradient (1300–2100 m) for green and brown morphs. (a) Total predation probability decreased with elevation, with no effect of color or elevation $\times$ color interaction. (b) Invertebrate predation showed the same declining trend with altitude, again with no color effect. (c) Bird predation peaked at intermediate elevations and was absent at 2100 m, with no significant influence of color or elevation $\times$ color interaction.

prey mortality may change markedly during the growing season (Rommel et al., 2009). In the present study, however, the lack of detectable variation among sampling sessions suggests that the observed altitudinal pattern was consistent across the sampling period. Our results help fill an important gap in the literature: trophic dynamics in high-mountain ecosystems remain poorly explored, and only a few studies have applied standardised methods to quantify predation in these environments (Lövei & Ferrante, 2017).

4.2. Invertebrate predation

Invertebrates represented the dominant predator group, responsible for over 85% of recorded attacks. This finding supports hypothesis H2, which predicted that invertebrates would cause a greater number of attacks than birds, and aligns with previous studies showing a strong response of arthropods to artificial models (Valdés-Correcher et al., 2022). However, our data do not allow us to determine whether this pattern was due to variation in the local abundance or activity of arthropod predators, and consequently in their probability of encountering the artificial caterpillars. Here as well, invertebrate predation decreased significantly with altitude, suggesting that the distribution of arthropod communities may play an important role in shaping predation risk.

The sharp decline in predation intensity with elevation aligns well with known patterns in alpine ant ecology. In coniferous forests of the Alps, mound-building red wood ants (*Formica rufa* group) are the dominant predatory arthropods and exert strong direct and indirect effects on other arthropods (Guariento et al., 2018). Their conspicuous presence at lower sites, together with known elevational patterns in ant communities, suggests that wood ants may have contributed substantially to the higher attack rates recorded there.

Ant communities generally decrease in abundance and diversity with increasing elevation (Guariento & Fiedler, 2021; Schifani et al., 2024), and red wood ants follow this same trend, reaching peak densities in montane and lower subalpine forests. This ecological pattern provides a plausible explanation for the reduced predation pressure observed at the highest elevation in our study.

This explanation is also consistent with broader evidence that lower temperatures along altitudinal and latitudinal gradients curb invertebrate activity and predation efficiency (Roslin et al., 2017).

4.3. Bird predation

Given that only 42 bird attacks were recorded across the entire experiment, patterns of bird predation along the elevational gradient should be interpreted cautiously. Moreover, bird attacks on sentinel prey were completely lacking at the 2100 m site. This pattern is consistent with well-known elevational constraints on forest passerine communities in the European Alps. Many forest-associated species exhibit their highest abundances at mid-elevation zones, where vegetation structure and trophic resources are most favourable, but decline sharply towards and above the tree line (García-Navas et al., 2021; Mermillon et al.,

2021). High-altitude subalpine habitats are typically more open, structurally simplified, and subject to harsher climatic conditions, factors that may influence the composition and activity of bird communities. Although birds can remain active even under relatively cold conditions in order to meet their energetic requirements, the combined effects of habitat structure and resource availability may reduce predation pressure at higher elevations (Mollet et al., 2018). Broader biogeographic syntheses further show that climatic severity and reduced resource availability strongly limit the presence and activity of many forest passerines at higher elevations (Chamberlain et al., 2023). Together, this evidence suggests that the lack of bird attacks at 2100 m in our study is consistent with the ecological and climatic constraints that shape alpine bird assemblages along elevational gradients. An additional factor that may help explain the relatively low bird predation rate observed at the lowest site is local environmental conditions. This site was located close to human infrastructure and partially influenced by nearby open areas, which may affect bird activity or habitat use. Anthropogenic disturbance has been shown to influence trophic interactions in some systems, although further data would be required to test this hypothesis directly. However, given the limited number of recorded bird attacks, these ecological mechanisms should be regarded as plausible interpretations rather than as mechanisms directly demonstrated by the present experiment.

4.4. Lack of a colour effect

Contrary to hypothesis H3, model colour (green vs. brown) did not affect attack probability, neither in terms of total predation nor with respect to specific predator groups. The absence of a detectable colour effect suggests that model colour alone was not a major determinant of attack probability under the conditions of this experiment. Because background colour was not quantified at individual model locations, we cannot determine whether the degree of visual contrast or camouflage experienced by green and brown models was fully comparable among sites. Nevertheless, model colour itself did not emerge as a significant predictor of attack probability in our experiment. Many arthropod predators rely primarily on tactile cues or direct contact during foraging, detecting prey through surface exploration rather than visually guided attacks. For invertebrates, this pattern is likely related to the fact that ants of the genus *Formica* were the most conspicuous predatory invertebrates observed along the transect. Although individual attacks cannot be attributed with certainty to specific arthropod taxa, their ecological dominance and generalist predatory behaviour make them plausible contributors to a substantial proportion of the observed attacks. Evidence for true colour vision in mound-building wood ants remains limited (Yilmaz & Spaethe, 2022). Other visually oriented predators, such as paper wasps (Vespidae), often rely on a combination of visual and olfactory cues to detect prey, and their foraging behaviour is known to depend strongly on chemical signals or movement rather than on static visual stimuli alone (McPherson & Mills, 2007; Sheehan et al., 2014). Given that vespid colonies are still small and

occur at low density in early summer in mountain forests, these predators were unlikely to contribute substantially to attack rates in our experiment. For birds, model colour may have been less influential than other visual or behavioural characteristics of natural prey, such as movement, posture, or shape. However, the small number of recorded bird attacks limits the strength of inference regarding colour responses in this predator group. A similar absence of colour effects was reported by Seifert et al. (2015), who found no significant difference in attack rates between green and brown artificial caterpillars, either for overall predation or for attacks attributed separately to arthropods and birds. Given that green and brown represent common colourations among caterpillars, these findings suggest that, as long as artificial prey falls within a typical range of caterpillar colouration, colour per se may have relatively little influence on their overall probability of being attacked.

4.5. Validity of the sentinel prey technique

Artificial prey was frequently attacked despite the absence of olfactory or behavioural cues, supporting the usefulness of the sentinel prey method also in alpine environments. The collected data support the use of plasticine models as a useful proxy for comparing relative predation pressure among sites, while acknowledging their intrinsic limitations, such as the probable underestimation of actual predation intensity under natural conditions (Lövei & Ferrante, 2017; Nagy et al., 2020).

Overall, the good replicability and sensitivity of the method suggest that it could also be readily incorporated into long-term monitoring programmes of mountain trophic networks, especially in relation to climate change.

4.6. Study limitations

The present study has several limitations that should be considered when interpreting the observed elevational pattern. Because artificial caterpillars were deployed exclusively on tree trunks and branches at approximately 1–2 m above ground, the experimental setup sampled only a subset of the potential natural predator community. Predators active on woody vegetation were more likely to encounter the models, whereas ground-dwelling predators, including carabid beetles, vagrant spiders and other epigeic arthropods, were likely to be underrepresented. Consequently, the recorded attack rates should be interpreted as relative predation pressure exerted by the predator groups effectively sampled by the experimental design, rather than as an estimate of predation by the entire predator community.

This limitation is particularly relevant when interpreting the decline in predation with elevation. Ants of the genus *Formica* were among the most conspicuous predatory invertebrates observed along the transect and were only rarely observed at 2100 m. Moreover, ant abundance and diversity are known to decline along elevational gradients (Guariento & Fiedler, 2021; Schifani et al., 2024). The reduction in attack rates at higher elevations may therefore partly reflect elevational changes in the abundance and activity of ants and other vegetation-foraging predators,

rather than an elevation effect acting uniformly across all predator guilds.

A further limitation concerns the absence of spatial replication across multiple mountain slopes. The experiment was conducted along a single south-facing altitudinal gradient, which allowed us to maintain broadly comparable exposure conditions and a standardised experimental protocol along the transect. However, without replication across independent slopes or mountain systems, the effect of altitude cannot be fully disentangled from other site-specific environmental factors that may covary with elevation.

Local anthropogenic context also differed among sites, particularly at lower elevations, but anthropogenic influence was not quantitatively measured. Its potential contribution to variation in predation therefore cannot be separated from the effects of elevation or other site-specific characteristics and should be regarded only as a possible source of variation.

Consequently, the results should be interpreted as evidence from a case study within a single alpine landscape rather than as a universal pattern. Nevertheless, the standardised design provides useful baseline data on predation pressure across an alpine elevational gradient and can contribute to future comparative studies and meta-analyses.

4.7. Ecological implications and future perspectives

These results offer important insights into how fundamental ecological processes, such as predation, respond to environmental gradients and high-altitude conditions. The observed decrease in attack rates at higher elevations suggests that insect prey occurring on woody vegetation may experience weaker top-down pressure from the predator groups responding to our experimental design. This variation in predation pressure may also have broader evolutionary implications, potentially influencing the strength of selective pressures on prey defences, behaviour, or life-history strategies across elevations. Similar attenuations of biotic interactions at higher elevations have been observed elsewhere, with insect herbivory often declining along altitudinal gradients (Kozlov et al., 2022), though opposite patterns have also been documented in some systems (Paudel et al., 2021). High-elevation arthropod communities are further shaped by strong environmental filtering (Shah et al., 2020), and the activity of predators and parasitoids is strongly constrained by temperature and habitat structure (Corcos et al., 2018), supporting the interpretation of reduced predation pressure in alpine environments.

In a global warming context, it is likely that many predator species (particularly arthropods) shift their altitudinal ranges upward, potentially increasing predation risk at elevations that currently experience rather low top-down control. However, predators and prey may not shift their distributions at the same rate under climate warming, potentially leading to temporary mismatches in trophic interactions along elevational gradients. Such upslope movements have already been widely documented for montane insect communities globally (McCain & Garfinkel, 2021), and warming-driven changes in the distribution and ecological roles of high-elevation arthropods are considered

a key mechanism reshaping alpine food webs (Shah et al., 2020). Therefore, the data collected here represent a valuable baseline for future comparisons.

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Table S1. Omnibus test results from the binomial generalised linear model used to assess the effects of sampling session, elevation, and prey colour on predation probability. Sampling session corresponded to the three exposure dates: 24 May, 10 June, and 20 June 2025. The response variable was predation presence/absence for each artificial prey model. χ^2 values, degrees of freedom, p-values, and η^2 effect-size estimates are reported.

	χ^2	df	p	η^2
Date	0.195	2	0.907	1.96e–4
Elevation	56.150	4	<0.001	0.05648
Colour	1.031	1	0.310	0.00104



Fig. S1. Vegetation structure at the highest-elevation experimental site (2100 m a.s.l.). The site consisted of a relatively open Swiss stone pine (*Pinus cembra*) forest stand surrounded by alpine pasture. The forest was fenced and therefore physically separated from livestock grazing.