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Research article

Predation risk in a migratory butterfly increases southward along a latitudinal gradient

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In migratory insects performing multigenerational migration, such as the painted lady butterfly *Vanessa cardui*, successive generations face a wide variety of predator communities and may be subject to different predation risks. Here, we analyze the pattern of wing damage of over 2000 butterflies to investigate, for the first time, the risk of predation of adult painted ladies across a latitudinal range of ca 3500 km extending from the northern Mediterranean through the Maghreb to sub-Saharan West Africa. Large number of butterflies showed substantial wing damage attributable to failed attacks, with birds, mantids and lizards being the most likely predators. The risk of attack increased towards the equator, even after controlling for wing wear. In addition, there was a strong effect of butterfly size on predation risk, with larger butterflies facing a higher risk compared to their smaller counterparts, and clear evidence that females suffered more attacks than males. Although size is a major factor, latitude was a stronger predictor of predation risk across the migratory system, as evidenced by greater wing damage in butterflies at lower latitudes, even though their size notably decreased. These results raise an interesting evolutionary conflict, with a tradeoff between size and predation risk, as larger butterflies are likely to be more fecund and efficient in migratory flight but, at the same time, more vulnerable to predation.

Keywords: bird predation, body size, butterfly wing damage, insect migration, latitudinal trend, *Vanessa cardui*

Introduction

Migratory insects provide a valuable ecosystem service by transporting large amounts of organic matter across habitats and regions, which has important consequences for the structure of local food webs (Hu et al. 2016, Satterfield et al. 2020). One such insect is the painted lady butterfly *Vanessa cardui*, which in some years migrates in large



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numbers and reaches high densities in the areas of arrival (Hu et al. 2021), thus constituting a potential resource for numerous predators (Hawkes et al. 2022).

This multi-generational migratory butterfly performs long-range movements throughout its almost cosmopolitan range (Stefanescu et al. 2013), tracking favorable regions for breeding as the season progresses (Menchetti et al. 2019). Migration in the Western Palearctic-Afrotropical system encompasses a latitudinal range of 6000–7000 km, from the tropical region near the equator in the winter period (Talavera et al. 2023) to the European Nordic countries during the summer peak (Stefanescu et al. 2013). Adult butterflies live up to four weeks. In most cases, they leave the area where they were born soon after emergence to breed in distant regions, after completing one leg of the migratory circuit (Stefanescu et al. 2021). Consequently, successive generations face different environmental conditions, including a wide variety of predators.

Although data on the natural enemies of adult painted ladies are rare, wing damage is frequently observed (Korkmaz et al. 2022), suggesting that predation of the adult stage, especially by birds (Stefanescu 2024), is a common phenomenon. Here, we tested several predictions about predation risk in relation to the migratory behavior and morphology of this butterfly. Our approach involved the assessment of wing damage in over 2000 individuals collected over seven years

in three regions spanning a latitudinal range of ca 3500 km, extending from the Mediterranean region to the subtropical Sudano–Guinean savannah.

First, we examined regional variations in wing damage as a surrogate of predation risk, expecting an increase in the subtropical region, following the hypothesis that biotic interactions intensify towards the tropics in parallel with the increase in biodiversity (Schemske et al. 2009). Second, we tested the role of prey body size, expecting predation risk to increase in larger butterfly individuals, which may represent more rewarding prey (Turner 1982). Third, we hypothesized that predation risk is sex-dependent, with females facing a greater risk than males, based on previous work on other butterfly species (Ide 2006). We conclude by discussing trade-offs between predatory pressure and other evolutionary constraints on the painted lady body size along its migration route.

Material and methods

Butterfly collection and sampling regions

Between 2015 and 2023, a total of 2276 painted ladies were collected in three regions (Fig. 1, Supporting information). Sampling was designed to obtain representative collections of

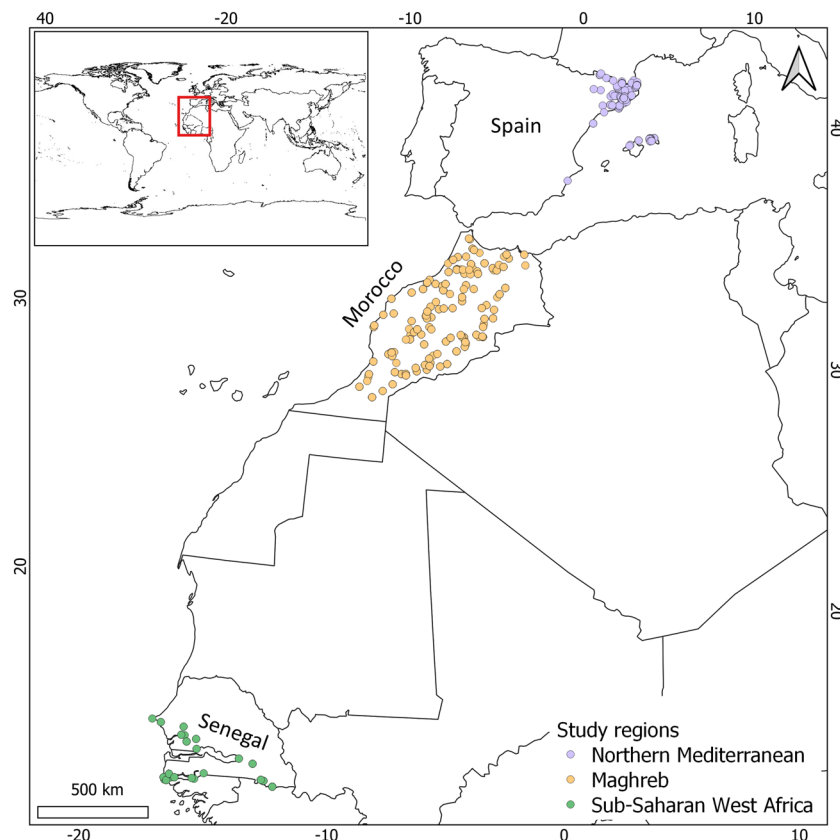


Figure 1. Distribution of samples in the study regions. Each dot represents a location where butterflies were collected and analysed. For detailed information on the number of butterflies sampled in each region, period and year, see the Supporting information.

the study regions, while avoiding spatial and temporal biases: 1) northern Mediterranean, 891 butterflies from 102 sites in northeast Spain (38–43°N, 0–4°E); 2) Maghreb, 1247 butterflies from 141 sites in Morocco (28–35°N, 2–11°W); and 3) sub-Saharan West Africa, 138 butterflies from 22 sites in Senegal (11–15°N, 11–17°W). More detailed coordinates can be found in Dryad, <https://doi.org/10.5061/dryad.fbg79d3t>. In the northern Mediterranean, butterflies were collected each month from March to October; in Morocco, they were collected in autumn (October–November), spring (April), and winter (January–February); and in Senegal, in October.

Butterflies were sexed, and their wings were removed and stored in glassine envelopes for further measurements. To account for the potential influence of age on wing damage, wing wear (i.e. a surrogate of age) was assessed on a scale from 1 to 5, as described in [Stefanescu et al. \(2016\)](#). Wing size was measured with a calliper (to the nearest tenth of millimeter), from the apex to the insertion on the thorax for either forewing.

Wing damage measurements and predation risk

Wing damage was measured for each of the four wings and quantified as the percentage of wing-area loss using digital images and the open-source platform for biological-image analysis Fiji ([Schindelin et al. 2012](#); Supporting information).

As wing damage can result from both wear and tear associated to routine behavioral activities, or be the consequence of unsuccessful predator attacks ([Korkmaz et al. 2022](#)), we examined the distribution of wing area loss through histograms (Supporting information). Taking an average of area loss across the four wings, more than half ($60.1 \pm 10.3\%$) of the sample showed no loss or a loss of less than 1% on their wings, while the remaining butterflies showed a gradual decrease from 1–2% wing area loss ($10.4 \pm 1\%$ of individuals) to 40–50% loss in rare and extreme cases ($2.2 \pm 2.1\%$ of individuals). This pattern suggests that wing damage in the first interval is simply explained by wear and tear from normal activities as the butterfly ages, whereas values below 99% of the wing area may often be related to unsuccessful predator attacks. Therefore, predation risk was treated as a binary variable, with individuals classified as non-attacked (i.e. 0–1% wing area loss, calculated as the average of the four wings) or attacked ($> 1\%$ wing area loss). Although this method is likely to overestimate the frequency of attacks, the error is distributed homogeneously across the entire sample and does not affect the hypotheses being tested.

It is important to recognize that the actual predation rate cannot be directly inferred from wing loss data alone ([Bengtson 1981](#), [Burger and Gochfeld 2001](#)). Despite this, when accounting for the degree of wing wear, the incidence of wing loss is likely correlated with the frequency of predator attacks, thereby serving as a proxy for assessing predation risk. Nevertheless, for comparative purposes, we also used other more restrictive thresholds of wing damage to define what was considered as evidence of failed attack (below).

Statistical analysis

A logistic regression model confirmed a high correlation between the binary predation variable and wing wear ($\chi^2(8) = 835.45$, $p < 0.001$; Supporting information). Older individuals accumulate not only more wear over their lifetime, but also a greater chance of being attacked. Therefore, we controlled for butterfly age by treating wing wear as a random factor in the models.

Predation risk was analysed by means of generalized linear mixed models (GLMMs) using a binomial distribution and logit link function, with wing wear and year as random factors.

A first model tested for differences in predation risk between regions, seasons, the interaction between regions and seasons, sex and wing size. We used data from the northern Mediterranean and the Maghreb, distinguishing between spring (March–June) and autumn (July–November), which correspond to the seasons when painted ladies are more abundant in these two regions, respectively ([Stefanescu et al. 2017](#), [Hu et al. 2021](#)). In a second model, data from Senegal – where painted ladies only occur from August to November ([Talavera et al. 2023](#)) – were included, and the analysis was restricted to the autumn period to ensure comparability between regions.

To explore how sensitive were the results to the choice of the 1% threshold, a second set of models was run with increasingly restrictive thresholds (5, 10 and 15%) (Supporting information).

All analyses were performed with R ver. 4.2.1 (www.r-project.org). The ‘glmmTMB’ package was used for the GLMMs ([Brooks et al. 2017](#)).

Results

A considerable proportion of butterflies presented some extent of wing damage ([Fig. 2](#), Supporting information), with 39.9% of the 2276 individuals having lost more than 1% of their total wing surface. Across all regions and periods combined, 30.5% of forewings had a loss greater than 1%, while this figure rose to 48.2% for the hindwings. Therefore, wing damage was recorded approximately 1.5 times more often on the hindwings than on the forewings. Likewise, the total area loss was higher in the hindwings than in the forewings ([Fig. 3](#), Supporting information). The highest recorded values for wing area loss were 56.8% in the forewing and 92.6% in the hindwing.

Predation risk models

The binomial model of predation risk considering the two more comprehensively sampled regions indicated that predation was more severe in larger butterflies, and in the Maghreb than in the northern Mediterranean. No differences were found between sexes, seasons (spring and autumn), or the interaction between region and season ([Table 1](#), model 1). According to



Figure 2. Examples of wings of painted lady showing signs of unsuccessful attacks by predators. Top row: butterflies with asymmetrical wing damage; bottom row: butterflies with symmetrical wing damage. Photo: Jordi Jubany.

the model, a 1 mm increase in wing size resulted in a 12.2% increase in predation risk. We obtained similar results when we added the data from Senegal but restricted the analysis to the autumn period (Fig. 4, Table 1, model 2). Wing size and region were significant predictors of predation risk, with larger butterflies and those caught in Morocco and Senegal suffering heavier predation pressure (e.g. a butterfly in Senegal is 180% more likely to be attacked than one in the Mediterranean).

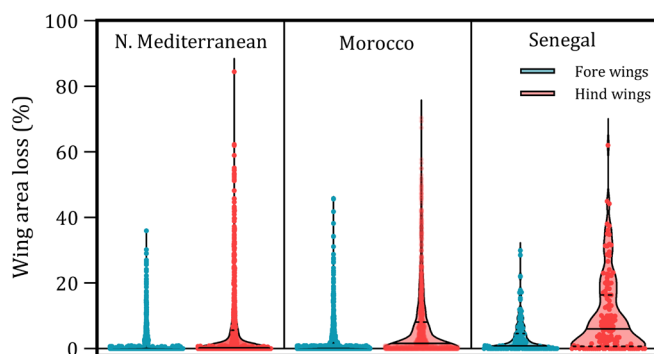


Figure 3. Wing area loss recorded in the forewings and in the hindwings of painted ladies in the three sampled regions: northern Mediterranean ($n=891$), Morocco ($n=1247$), and Senegal ($n=138$). In the violin plots, dots correspond to average values of the two fore- or hindwings, the continuous line to the median, and the dashed lines to the 25 and 75% quartiles.

The effect of wing size remained significant when predation risk was modelled using thresholds of 5 and 10% of wing area loss to classify a butterfly as attacked (Supporting information). On the other hand, regional differences were not significant for these more restrictive thresholds. However, when the frequency of attacked butterflies was plotted against the wing damage threshold, predation risk remained higher in Morocco than in the Mediterranean up to a threshold of ca 8%, and much higher in Senegal than in the other two regions up to a threshold of ca 24% (Supporting information). Finally, the effect of sex, for which the evidence was weak for the models considering the 1% threshold, became highly significant at the highest thresholds (10 and 15%; Supporting information).

Discussion

We found appreciable wing damage in painted ladies, with approximately 40% of the individuals showing at least 1% of total wing area loss. Taking this as evidence of failed predator attacks, we found that predation risk was strongly related to wing size, region and, to a lesser extent, sex, consistent with the proposed hypotheses. Our findings are discussed below in an ecological context and in relation to the migratory strategy of the species.

Table 1. Summary of predation risk models. Model 1 used data from the northern Mediterranean (Med.) and Maghreb (Mor.) in autumn and spring; and model 2 used data of all regions, northern Mediterranean, Maghreb and Senegal (Sen), in autumn.

Predictor	Estimate	SE	z-value	p-value
Model 1. Northern Mediterranean versus Maghreb in autumn and spring				
Region (Med. versus Mor.)	0.477	0.165	2.896	0.003
Season (autumn versus spring)	0.112	0.172	0.647	0.517
Sex (female versus male)	−0.079	0.114	−0.694	0.487
Wing size	0.115	0.03	3.862	0.001
Region × season	−0.272	0.274	−0.991	0.321
Model 2. Northern Mediterranean versus Maghreb versus Senegal in autumn				
Region (Med. versus Mor.)	0.522	0.171	3.05	0.002
Region (Med. versus Sen.)	1.03	0.435	2.365	0.018
Region (Mor. versus Sen.)	0.507	0.409	1.238	0.216
Sex (female versus male)	−0.153	0.134	−1.141	0.253
Wing size	0.115	0.0372	3.108	0.002

Predation risk quantification

Previous work analyzing butterfly predation as a function of wing damage suffers from the serious shortcoming of not using a clear definition of what actually constitutes a beak mark or the sign of an attack, and how it should be quantified. Therefore, the figures given in the literature cannot be reliably compared between studies, as they usually depend on a subjective assessment by the researcher (Halali et al. 2019, Molleman et al. 2020).

In our study, 39.9% of butterflies showed wing losses greater than 1% which, based on the distribution of wing area loss in the entire sample, were distinguished from mechanical wear of the wing and were considered a likely sign of a failed attack. We acknowledge that this method is less conservative than subjective judgments such as those used in other studies, and likely overestimates predation events. The percentage of butterflies classified as attacked was reduced to 25, 14 and 8%, when using other arbitrary thresholds of 5, 10 and 15% wing loss, respectively. Figures reported in the literature range from 5 to 25% for species such as *Lethes diana* in Japan (Ide 2006), *Maniola jurtina* in Sweden (Bengtson 1981), or *Cercyonis pegala* in the northeastern USA (Bowers and Wiernasz 1979), but can be as high as 40–46% (i.e. more

than our own estimates for a threshold of 1%) for Japanese black swallowtail butterflies (Kiritani et al. 2013).

Wing damage and potential predators

The pattern of wing damage fully coincided with a previous analysis based on a much smaller sample (Korkmaz et al. 2022). It was more frequently recorded and was more extensive on the hindwings than on the forewings, a pattern that has also been found in other butterflies (Molleman et al. 2020) and which can be explained by the mechanics of flight (Le Roy et al. 2019) and by ecological factors. There are various reasons why predators inflict damage more frequently on the hindwings than on the forewings. Thus, it is expected to occur when predators fail in their attack when pursuing butterflies in flight (Molleman et al. 2020), but also when they approach perched butterflies from behind to minimize their detection. It could even be a consequence of predators directing their attacks preferentially towards the hindwings due to the presence of small marginal eyespots on the ventral side, such as those present in the painted lady, intended to attract predator attention (i.e. the deflection hypothesis; reviewed by Kodandaramaiah 2011). Finally, the higher frequency of hindwing damage may also reflect less

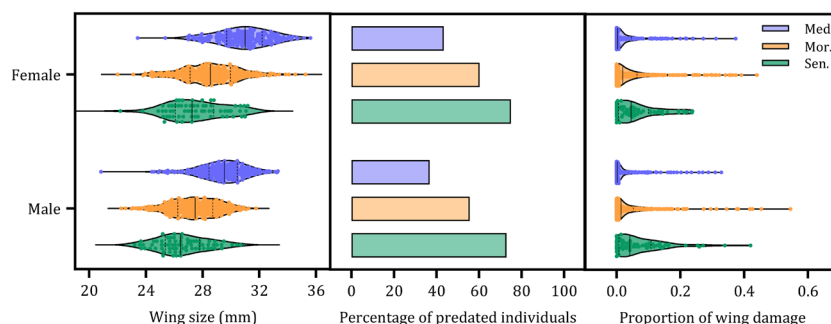


Figure 4. Differences in wing size and predation risk of adult painted ladies between northern Mediterranean (Med.), Morocco (Mor.) and Senegal (Sen.) based on autumn samples. Results are shown for both the percentage of unsuccessful predated attempts (based on a wing loss threshold of 1%) and proportion of wing damage. Size distribution shows a clear increasing trend with latitude and, at the same time, a larger size of females than males. In the violin plots, dots correspond to average values of the two fore- or hindwings. The continuous and discontinuous lines in the violin plots correspond, respectively, to the median and to the 25 and 75% quartiles.

severe survival consequences compared to forewing damage (Molleman et al. 2020, Korkmaz et al. 2022).

Butterfly wing damage is often attributed to bird attacks and is referred to as 'beak marks' (Carpenter 1935, Shapiro 1974, Smith 1979, Robbins 1981, Ide 2006). Butterflies that manage to escape an attack by a bird can present this type of marking, as confirmed by field observations (Burger and Gochfeld 2001). Lizards are other potential predators that cause similar damage, especially in the tropics (Ehrlich and Ehrlich 1982, Halali et al. 2019). Furthermore, some predatory insects such as mantids and dragonflies are known to prey on adult butterflies (Sang and Teder 2011, López-Palafox and Cordero 2017) and therefore could also be responsible for the observed wing damage.

We believe that bird predation and beak marks are the most plausible explanation for wing damage in our study. This conclusion relies on actual observations of successful and unsuccessful attacks by at least 32 bird species, including a notable diversity of morphologies and prey-capture techniques, suggesting that predation by birds is a common phenomenon (Stefanescu 2024). However, we also observed three species of mantids and one species of assassin fly preying on adult painted ladies in Morocco, and thus have direct evidence that these predatory insects could play a prominent role in the studied system. Additional contributions by lizards cannot be discounted, but we lack direct observations or supporting literature to confirm their roles.

Regional differences in predation risk

As predicted, the risk of attack increased towards the equator, even after controlling for wing wear. This was true when data for all seasons from the northern Mediterranean and Morocco were compared, as well as when autumn data for the three study regions along the entire latitudinal gradient (11°–43°N, including Senegal) were analysed. Moreover, although regional differences were no longer significant in the models that used more conservative thresholds to define predation events, the pattern remained essentially unaltered (Supporting information).

The high incidence of attacks in Senegal may relate to the much more diverse insectivorous bird fauna in this subtropical area. Thus, according to Billerman et al. (2022), 101 species in Senegal include lepidopterans in their diet, compared to only 54 species in Spain and 51 in Morocco (Supporting information). These data are far from optimal, as they do not distinguish preference for adult butterflies among bird species and do not list some species we have confirmed as predators of the painted lady (Stefanescu 2024). Nevertheless, they show that in the subtropical region there are almost twice for some of the potential predator species as in the other two regions. The higher predation risk in Morocco compared to Spain, even if the number of potential bird predators is very similar, could be explained by a higher diversity of birds that specialize in catching adult lepidopterans (e.g. seven species of *Oenanthe* in Morocco but only three in Spain, two species of *Merops* in Morocco against a single Spanish species).

Predation by lizards is also likely to occur more commonly in Morocco than in the northern Mediterranean, given the more diverse fauna in the former region, including species known to prey on adult butterflies (Schleich et al. 1996).

In addition, these regional trends may also relate to a greater diversity and abundance of key insect predators at lower latitudes. For example, in the specific case of mantids and assassin flies, which we were able to confirm as predators of the painted lady, Battiston et al. (2010) and Londt and Dikow (2017) mention clear patterns of greater richness in warmer regions and/or arid regions towards the tropics.

Here, we discuss predator diversity as a potential explanation of predation pressure, but it is important to consider that predator abundance may be a more important factor (Nyffeler et al. 2018). One bird species that occurs at high densities could have more significant impacts on a prey population than multiple predator species occurring at low densities. However, such data on predator abundance are currently unavailable. Additionally, the availability of alternative prey likely also affects predation pressure (Barraquand et al. 2015). Nevertheless, as the higher predation risk in Morocco compared to Spain was independent of season, it is unlikely that the latitudinal trend is driven by seasonal availability of alternative prey.

Our findings are in line with the hypothesis that biotic interactions increase towards the equator, paralleling the overall increase in diversity at lower latitudes (Schemske et al. 2009). However, it should be noted that two recent studies using artificial caterpillar models nuanced this geographic trend: they claimed increased overall attack pressure on arthropods, but no increase in predation by birds and mammals specifically, which remained constant or even increased at higher latitudes (Roslin et al. 2017, Zvereva et al. 2019). We therefore call for future studies focusing on predation of adult butterflies to confirm the pattern we found.

Wing size effect on predation risk

Regarding the second hypothesis, our models (even those using higher thresholds of 5 and 10% of wing loss) consistently indicated a strong effect of butterfly size on predation risk. Regardless of the dataset, butterfly size emerged as a highly significant factor, with larger butterflies facing greater risk of predation, as predicted. Other butterfly studies present compelling data supporting the same result (Smith 1979, Kiritani et al. 2013), suggesting that this is indeed a robust pattern. The preference of predators for larger butterflies could be explained in terms of the major profitability of larger prey and the optimal foraging theory (Turner 1982). Alternatively, it could be associated with differences in butterfly escape abilities that are linked to wing morphology and parameters such as the position of the body mass center or wing load (Chai and Srygley 1990, Srygley and Dudley 1993). Indeed, we found for the painted lady a significant negative linear relationship between the thorax-to-abdomen weight ratio and wing size (Supporting information). This implies that larger butterflies have relatively heavier abdomens and, therefore,

a predictably poorer maneuverability and escape capabilities when faced with predator attacks. Experiments similar to those performed by [Srygley and Dudley \(1993\)](#), presenting painted ladies of different sizes to an aerial predatory bird, are needed to clarify these questions.

Although size is a major factor, it should be noted that regional differences are more important than morphology in predicting predation risk, because wing damage increased at lower latitudes, even though, in parallel, there was a strong decrease in size ([Fig. 4](#)). Indeed, the smaller equatorward size is puzzling, as larger body size tends to correlate with higher fecundity in insects, especially females ([Allen et al. 2011](#)), and the larger wings with longer migratory distances in migratory butterflies ([Altizer and Davis 2010](#)). We can speculate that the trend of decreasing butterfly size at lower latitudes, contrary to expectations based on migration distance ([Stefanescu et al. 2016](#)) and flight efficiency ([Le Roy et al. 2019](#)), could be the result of a trade-off between the benefits of a larger size on migration and the increased risk of predation.

Sex-related differences in predation risk

Our findings suggest that the risk of predation is higher for females than for males. The effect of sex was only marginally significant in some models when butterflies were classified as attacked based on a threshold of 1% of wing area loss, but it became highly significant for higher thresholds of 10 and 15% (Supporting information). Although sexual dimorphism in the painted lady is less pronounced compared to other butterflies, certain differences may still contribute to the differential predation risk between sexes. For instance, thorax weight is relatively lower and abdomen weight relatively higher in females than in males, suggesting that they are less powerful fliers (Stefanescu and Colom, unpubl.). Moreover, females are larger than males (29.6 ± 2.3 versus 28.4 ± 2.01 mm), and the thorax/abdomen ratio decreases with size (Supporting information) which, according to bird predation experiments ([Srygley and Dudley 1993](#)), suggests a greater risk of predation in females. However, in addition to morphological reasons, behavioural differences probably also make females easier targets for predators. In the painted lady, males do not search for females but, instead, establish and defend territories in the afternoon by fast, unpredictable, acrobatic flights. Females, on the other hand, spend more time nectaring on flowers (where they become a relatively easy target for birds and sit-and-wait predators such as mantids), but they also make regular slow-searching flights. These flights are followed by short stops on the host plants at the time of oviposition, when females remain with closed wings and become a more predictable and vulnerable prey. In this respect, females tended to show greater symmetrical wing damage than did males ([Fig. 2](#), Supporting information), which is indicative of attacks on butterflies with closed wings ([Shapiro 1974](#)). Therefore, behavior may underlie the sex-based differential predation risk, and conducting experiments with captive butterflies and birds could provide valuable insights in this regard.

Implications in the migratory ecology of the painted lady

It is interesting to speculate whether our findings might have implications for the migration and population ecology of the painted lady. Although our data cannot be used to calculate actual predation rates, they suggest not only that adult butterflies are at considerable risk of predation, but that this risk decreases as populations move northward in their annual migration. New data are needed to confirm whether this trend continues at higher latitudes in continental Europe, where additional summer generations are completed each year ([Stefanescu et al. 2013](#), [Menchetti et al. 2019](#), [Hu et al. 2021](#)). However, if this were the case, greater survival of females could contribute to the net increase of the population at higher latitudes, especially considering the high fecundity of this species ([Stefanescu et al. 2021](#)), along with the extremely high availability of breeding habitat in central and northern Europe during the summer months ([Menchetti et al. 2019](#)). This situation would be comparable to that described for other multigenerational insects with similar migratory cycles ([Chapman et al. 2012](#), [Wotton et al. 2019](#)).

A final interesting aspect to explore is the extent to which predation interactions are magnified by the migration process itself. Direct interactions between co-migrants, including predation, are still poorly understood but possibly relevant for species involved in massive movements that converge in space and time ([Cohen and Satterfield 2020](#)). We have been able to document some cases of predation interactions between co-migrants in this study, such as the attacks suffered by migratory painted ladies by birds that were also migrating such as *Muscicapa striata*, *Merops apiaster* or *Apus apus* ([Stefanescu 2024](#)). However, new data are needed to quantify how these types of interactions contribute to the estimated predation risk.

In conclusion, this study suggests that bird predation on painted ladies is common, particularly in African regions. It also indicates that predation risk is higher in larger butterflies, possibly due to a reduced ability to escape, the preference of predators for larger prey, or a combination of both factors. Finally, it raises an interesting evolutionary conflict for migratory insects, with a trade-off between size and predation risk that may be particularly relevant in a butterfly, in which larger size likely facilitates more efficient migratory flight.

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Author contributions

Constanti Stefanescu: Conceptualization (lead); Data curation (lead); Funding acquisition (equal); Methodology (lead); Supervision (lead); Writing – original draft (lead). **Clăudia Pla-Narbona:** Data curation (equal); Formal analysis (supporting); Methodology (equal); Writing – review and editing (equal). **Andreu Ubach:** Investigation (equal); Methodology (supporting); Writing – review and editing (equal). **Crinan Jarrett:** Funding acquisition (equal); Resources (equal); Writing – review and editing (equal). **Justinn Renelies-Hamilton:** Conceptualization (supporting); Formal analysis (supporting); Investigation (supporting); Writing – review and editing (equal). **Pau Colom:** Conceptualization (equal); Data curation (equal); Formal analysis (lead); Investigation (supporting); Methodology (lead); Writing – review and editing (lead).

Transparent peer review

The peer review history for this article is available at <https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ecog.07308>.

Data availability statement

Data are available from the Dryad Digital Repository: <https://doi.org/10.5061/dryad.fbg79d3t> (Stefanescu et al. 2024).

Supporting information

The Supporting information associated with this article is available with the online version.

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