Temporal dynamics of arthropods at "Hoher Sonnblick" (3100 m.a.s.l.)

Sarah M. Wagner [1*], Jana S. Petermann [1]

Biodiversity loss is driven by landscape transformation, intensive agricultural practices, and climate change. Climate change-induced temperature increases are also causing shifts in the distribution of many temperature-sensitive animal and plant species. Alpine arthropod communities are particularly sensitive to such changes, as demonstrated by observations at the summit of Hoher Sonnblick (3106 m, Hohe Tauern National Park, Salzburg). This study aimed to analyze the effects of various environmental parameters on the occurrence, abundance, and temporal dynamics of arthropods, and to evaluate the effectiveness of different sampling methods. Over a 28-day period in July and August 2023, a total of 3002 arthropod individuals representing 109 morphospecies and 13 orders were identified. Temperature, wind speed, and relative humidity significantly influenced species richness and abundance, while heavy snowfall triggered a mass emergence of *Desoria saltans* (Collembola). The different trapping methods captured distinct arthropod assemblages: pitfall traps were particularly effective for ground beetles and spiders, whereas cross-window and Malaise traps mainly sampled dipterans and lepidopterans. However, all methods were susceptible to extreme weather conditions. A combination of sampling approaches provided the most comprehensive representation of alpine invertebrate diversity. These findings highlight the role of alpine summits as refugia for endemic species and potential stepping stones for range shifts under climate change. Their protection and ecological connectivity are crucial to buffer the impacts of ongoing environmental change.

Wagner SM & Petermann JS (2026) Zeitliche Dynamik von Arthropoden am „Hohen Sonnblick" (3100 m)

Der Verlust der Biodiversität wird durch Landschaftsveränderung, intensive Landwirtschaft und den Klimawandel vorangetrieben. Klimawandelbedingte Temperaturanstiege führen zudem zu Verschiebungen in der Verbreitung vieler temperaturempfindlicher Tier- und Pflanzenarten. Besonders sensibel reagieren alpine Arthropodengemeinschaften, wie sie am Gipfel des Hohen Sonnblicks (3106 m, Nationalpark Hohe Tauern, Salzburg) untersucht wurden. Ziel dieser Studie war es, die Effekte verschiedener Umweltparameter auf Vorkommen, Häufigkeit und zeitliche Dynamik von Arthropoden zu analysieren sowie die Effektivität unterschiedlicher Erfassungsmethoden zu vergleichen. Über einen Zeitraum von 28 Tagen im Juli und August 2023 wurden 3002 Arthropodenindividuen aus 109 Morphospezies und 13 Ordnungen gesammelt. Temperatur, Windgeschwindigkeit und Luftfeuchtigkeit beeinflussten Artenreichtum und Abundanz signifikant; starker Schneefall führte zu einem Massenauftreten von *Desoria saltans* (Collembola). Die verschiedenen Fangmethoden erfassten unterschiedliche Artengruppen: Barberfallen waren besonders geeignet für Laufkäfer und Spinnen, während Kreuzfenster- und Malaisefalle v. a. Dipteren und Falter erfassten. Alle Methoden erwiesen sich jedoch als wetteranfällig. Eine methodische Kombination bietet das vollständigste Bild der alpinen Wirbellosenvielfalt. Die Ergebnisse unterstreichen die Rolle alpiner Gipfel als Refugien von Endemiten und als potenzielle Trittsteine für Arten im Klimawandel. Ihr Schutz und die ökologische Vernetzung sind entscheidend, um klimabedingte Veränderungen abzufedern.

Keywords: arthropod communities, biodiversity, community ecology, high alpine areas, National Park Hohe Tauern, Sonnblick Observatory.

Received: 2025 06 26

DOI: https://doi.org/10.25365/azba.162.07

[1] Paris-Lodron-University Salzburg, Department of Environment and Biodiversity, Hellbrunnerstraße 34, 5020 Salzburg, Austria.

[*] Corresponding author: sarah_wagner@outlook.at

Introduction

Over the past century, rapid land use changes have led to a collapse in arthropod populations (Hallmann et al. 2017; Carson 2021), posing a significant risk to ecosystem functions (Ruczyński et al. 2020) and services. Particularly vulnerable are isolated areas such as mountain tops, which harbor numerous endemic species (Nagy 2003; Mertz 2017). These regions are limited in space and thus more susceptible to environmental changes caused by habitat fragmentation, the extensive use of pesticides, and climate change (Dietz & Kiefer 2024; Settele 2020).

The Alpine Arc has experienced an air temperature rise at a rate twice as high as the global average since the late 20th century (Streitberger et al. 2016; Jandl et al. 2024). The predicted temperature shift comes with consequences concerning distributions of species along the elevational gradient (Streitberger et al. 2016). These changes may increase competition pressures on endemics and other species with narrow ecological amplitudes (Hofer 2009; Singer 2016), possibly leading to their local extinction. Within central Europe, the highest number of endemic species can be found in Austria (Rabitsch & Essl 2009).

Alpine habitats are characterized by high wind velocities, rapid temperature drops, strong UV-radiation, and long periods where the soil is covered with snow or ice (Lee & Denlinger 1991; Mertz 2017). Over time, the central Alps produced a diverse ecosystem which is adapted to its harsh and unpredictable climate (Ernakovich et al. 2014). With climate change, thermosensitive species may migrate further upwards along longitudinal and elevational gradients (Kerner et al. 2023) to escape alternating environmental conditions. These changes may pose additional threats to high alpine species (Rabitsch & Essl 2009). Some species, especially Lepidopterans, migrate (Mazzucco 1975) which leads to swarming events possibly driven by shifting climate.

This project investigated arthropod diversity in a high alpine ecosystem to test how environmental factors influence arthropod diversity and community composition. It also compared different sampling methods to determine their effectiveness in harsh conditions and explored changes over time, including possible swarming events.

Our hypotheses were that 1) apparent arthropod abundance and richness change with environmental parameters (wind speed, wind direction, air temperature, soil temperature, relative air humidity, and weather) and across time, for example due to migratory or swarming events, and that 2) composition of trapped arthropods varies between trap systems based on the selectivity of each method.

Methods

Study area

The field work was conducted at the mountain top of "Hoher Sonnblick" in Rauris (province of Salzburg) at the Sonnblick Observatory (47.054039 North, 12.957729 East, Fig. 1) at an elevation of 3106 m.a.s.l. The observatory is situated within the National Park Hohe Tauern, Central Europe's largest contiguous national park (Stüber 1989; Hofer 2009) and supports

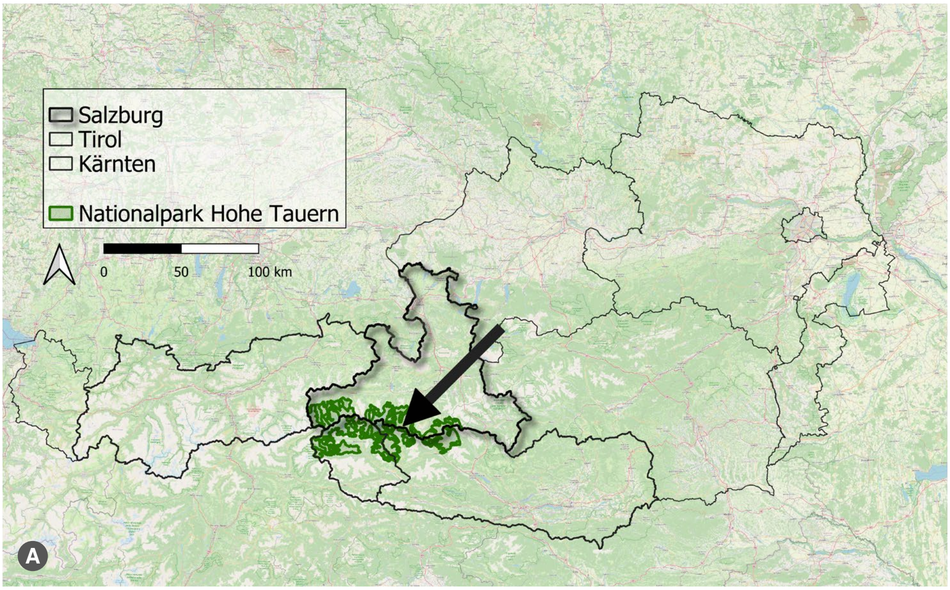

Fig. 1: Study location. **A)** Province of Salzburg with the Hohe Tauern National Park highlighted in green. The black arrow indicates the location of the Sonnblick Observatory at the border between the provinces of Salzburg and Carinthia. **B)** Sonnblick Observatory at the top of "Hoher Sonnblick" on the right, with the adjacent Zittelhaus alpine hut on its left side. © Sarah M. Wagner | **Abb. 1:** Untersuchungsgebiet. **A)** Bundesland Salzburg mit dem Nationalpark Hohe Tauern (grün hervorgehoben). Der schwarze Pfeil markiert den Standort des Sonnblick-Observatoriums an der Grenze zwischen Salzburg und Kärnten. **B)** Das Sonnblick-Observatorium befindet sich rechts im Bild auf dem Gipfel des Hohen Sonnblicks, links davon das angrenzende Zittelhaus. © Sarah M. Wagner

meteorological and ecological research (Ludewig et al. 2023). Adjacent to the station, there is a managed alpine hut which is operated during summer. The traps were either setup at the southern slope beneath the building complex or at the measuring terrace of the observatory. The study was executed for four consecutive weeks from 17th July to 14th August 2023.

Field data collection

Five different trap types were tested: snowfield traps, pitfall traps, cross-window traps, malaise traps and camera traps. For the snowfield traps, five areas of one square meter (Heiniger 1989) were flagged with a marker at each corner in the permanent snowfield on the southern slope (one to 50 meters apart). Samples were collected every 12 hours (morning and afternoon) where all visually detectable arthropods were collected from the snow surface with tweezers. The captured animals were stored in 70 % alcohol in Eppendorf tubes until further determination. Relocation of the transects was necessary during the sampling period due to fluctuations in snow cover. Fresh snowfall obscured snowfield traps located at glacier margins, where snow is typically retained year-round. To ensure that only newly deposited individuals were recorded, sampling was restricted to specimens present on the snow surface, and therefore only days without fresh snow were analysed.

Five pitfall traps were set up in snow-free areas with scarce vegetation to collect ground-dwelling insects (Heiniger 1989). The glass containers were buried in the ground and filled with 1–2 cm of 70%-Ethanol. A protective aluminium roof was used as a rain shield. Each trap was sampled daily, and the arthropods were stored in ethanol until further examination.

One cross-window trap was set up at the measuring terrace of the Sonnblick Observatory to intercept insects mid-flight. During the day (12 hours) it was equipped with a plastic container with ethanol as a collecting liquid for flying insects to drop into. In case of heavy rainfalls, the container was replaced with a net to avoid spill-over. These samples were stored for species determination at the lab in Salzburg. At night (12 hours) there was a light-source of different wave lengths (UV, green, blue) attached to attract nocturnal insects (Sheikh et al. 2016). For this setup the insects were guided through the funnel and into a net (instead of ethanol) to avoid wing scale loss and therefore enable identification of the moths which were expected during the night. Every morning, the moths were counted, identified with the ObsIdentify Application (Observation International 2023) and released.

One malaise trap (Fig. 2) was set up for catching flying insects and emptied daily (24-hour-intervals). The collecting vessel was filled with ≥ 96 %-Ethanol and pointed southwards (Ssymank et al. 2018) following the intrinsic need of insects of flying towards the sun.

Camera traps were used to quantify insect abundance via an analysis of nighttime pictures of the sky. A RICOH WG-6 Camera (Fig. 3) was set up at the measuring terrace of the Sonnblick Observatory following the script of Ruczyński et al. (2020). Each night, whenever possible according to the weather forecast, from about 9.30 pm (sunset) to 5.30 am (sunrise), five-minute-interval flash photography was used to record nocturnal flying insects in the night sky by counting individuals depicted as reflecting ellipses in the pictures. The vertically orientated camera was set to PF-focus and locking the ISO-value to 1600.

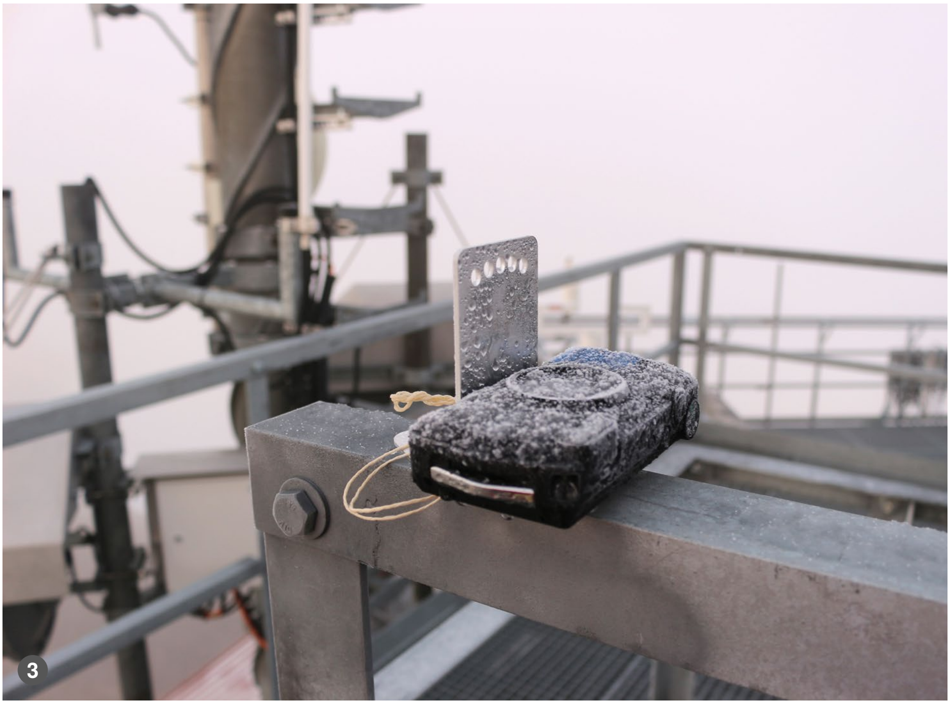

Fig. 2: Setup of malaise trap on the southern slope located below the Sonnblick Observatory. © Sarah M. Wagner | **Abb. 2:** Aufbau der Malaisefalle am Südhang unterhalb des Sonnblick-Observatoriums. © Sarah M. Wagner

Fig. 3: Setup of camera traps on the measuring terrace of the Sonnblick Observatory pointing straight up into the night sky. The camera lenses often froze overnight due to low temperatures and high humidity. © Sarah M. Wagner | **Abb. 3:** Kamerafalle auf der Messterrasse des Sonnblick-Observatoriums mit senkrechter Ausrichtung in den Nachthimmel. Aufgrund niedriger Temperaturen und hoher Luftfeuchtigkeit fror die Kameralinse nachts häufig. © Sarah M. Wagner

Environmental parameters (air temperature, relative humidity, wind speed, etc.) were measured in 30-minute-time-intervals by the Sonnblick Observatory and are publicly available via the Sonnblick Observatory Database (https://data.sonnblick.net/). The daily mean of each separate sampling period (24 h-intervals for comparability between trap types) for continuous parameters (air temperature, humidity, and wind speed) was calculated. Northness and westness was calculated from wind direction given in degrees (cardinal direction) and treated the same way as the continuous parameters. Additionally, three portable TFA analogue outdoor thermometers were placed at selected traps to measure soil temperature twice a day. However, heavy snowfall events occasionally buried the thermometers beneath the snow, thus, the thermometers could not be read (missing values).

Arthropod identification

All samples were determined to at least morphospecies level using a stereomicroscope at the laboratory of the University of Salzburg with 40x magnification and the following literature: Mandl & Schönmann 1978; Schedl 1980; Böhme et al. 1983; Mertz 2008; Müller-Motzfeld 2012; Lompe 2017; Schaefer 2018; Ko et al. 2018; Müller & Bährmann 2022.

Statistical analysis

Statistical analyses were conducted in R (R Core Team 2022, v3.8.2). Some sampling days were excluded because samples could not be collected due to adverse weather conditions (e.g., thunderstorms, extreme events). Abundance and (morpho)species richness were used as response variables, with air temperature, date (Julian days), relative humidity, weather categories (sunny, few clouds, cloudy, rainy, snowy, stormy), wind direction, wind speed, and, for the cross-window trap, lunar phase (new moon, half-moon, full moon) as explanatory variables. Given the non-normality, heteroscedasticity, and overdispersion of the data, generalized linear models (GLMs) with quasi-Poisson error distribution and a log link function were applied. In addition to an overall model testing for date, daytime, trap type, and the two-way-interaction of Julian day and trap type, separate GLMs were fitted for each trap type to test for the effect of environmental parameters on both diversity parameters. Due to the small sample size and the non-independence due to the repeated sampling, results must be interpreted with caution. The map was created in QGIS (QGIS Development Team 2024, *LTR version 3.40.8.*).

Results

During the sampling period of 28 consecutive days a total of 3002 individuals of 109 arthropod morphospecies (Table S2) were collected by 13 traps of five trap types. The samples ranged from 0 to 468 individuals and from 0 to 24 morphospecies. Collectively, 13 orders within three classes were found. Overall, 50 morphospecies were represented by a single individual.

Environmental effects on abundance and morphospecies richness

Starting off with a record high in temperature, the second and third week of the sampling towards the end of July 2023 were marked by snow fall at the summit. A minimum of -5.4 °C

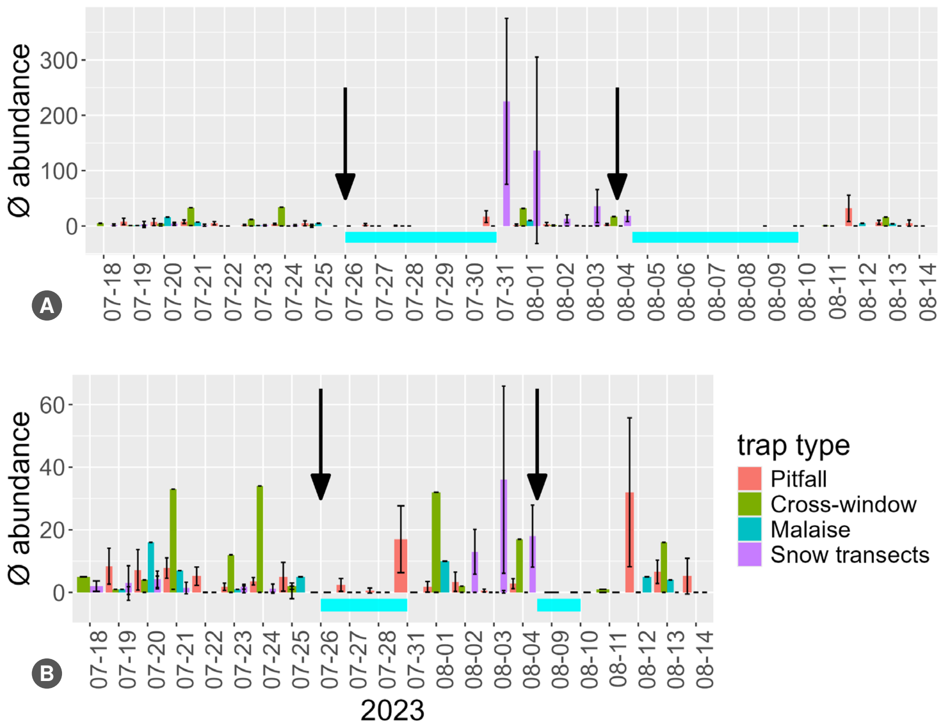

Fig. 4: Mean abundance per day and trap type with standard error for each method from 17th July until 14th August 2023: **A)** with complete data set, in **B)** the very abundant *Desoria saltans* (Collembola) were removed and missing data (days) excluded. Each method is depicted in a different colour (5 pitfall traps = red, 1 cross-window trap = green, 1 malaise trap = blue, 5 snowfield traps = purple). Two massive snowfall events on July 26th and August 4th (black arrows) were recorded, the ice blue bar beneath the x-axis highlights the period during which the soil remained widely snow-covered. | **Abb. 4:** Mittlere Häufigkeit pro Tag und Fallentyp mit Standardfehler für jede Methode vom 17. Juli bis 14. August 2023: **A)** mit vollständigem Datensatz, in **B)** wurden die sehr häufigen *Desoria saltans*-Individuen (Collembolen) entfernt und fehlende Daten (Tage) ausgeschlossen. Jede Methode ist in einer anderen Farbe dargestellt (5 Barberfallen = rot, 1 Kreuzfensterfalle = grün, 1 Malaisefalle = blau, 5 Schneefeldfallen = violett). Zwei massive Schneefallereignisse am 26. Juli und 4. August (schwarze Pfeile) wurden aufgezeichnet, der eisblaue Balken unter der x-Achse markiert den Zeitraum, in dem der Boden weitgehend schneebedeckt blieb.

and an increase in relative humidity was observed. Despite rising temperature towards the end of sampling period, the ground even at the exposed summit was still covered in snow.

The trap type had a highly significant effect on mean abundance where the highest number was found in pitfall traps (Table S2). High abundances were observable on July 31st and August 1st. Here, snowfield traps were predominantly populated by one species: the glacier flea *Desoria saltans* (Collembola) when snow melt events after heavy snowfall led to aggregation on the snow-surfaces (Fig. 4, first black arrow) on July 26th.

Tab. 1: Results of the overview model to depict differences between trap types: Results of the generalized linear model testing the effect of the environmental variables on arthropod abundance or arthropod species richness of the complete Sonnblick data set with Df = Denominator degrees of freedom and Df Resid. = Degrees of freedom of Residuals. Significant effects are indicated by bold font. | **Tab. 1:** Ergebnisse des Übersichtsmodells zur Darstellung von Unterschieden zwischen Fallentypen: Ergebnisse des generalisierten linearen Modells zur Prüfung des Einflusses von Umweltvariablen auf die Arthropodenpopulation bzw. den Arthropodenartenreichtum des gesamten Sonnblick-Datensatzes mit Df = Freiheitsgrade des Nenners und Df Resid. = Freiheitsgrade der Residuen. Signifikante Effekte sind durch Fettdruck gekennzeichnet.

		Abundance			**Species Richness**		
Variable	**Df**	**Df Resid.**	**χ^2**	**P-value**	**Df Resid.**	**χ^2**	**P-value**
Julian day	1	87	5.98	0.686	87	11.47	**0.005**
Trap type	3	84	609.42	**0.001**	84	256.33	**<0.001**
Daytime	1	83	1.24	0.854	83	0.22	0.788
Julian day: Trap type	3	80	135.53	0.295	80	23.826	0.005

For species richness (Table 1) the effects of Julian day, and trap type, as well as the two-way-interaction between trap type and Julian day were significant. At the beginning and towards the end of our study period the highest number of morphospecies could be collected, especially the pitfall traps and malaise trap collected the most species at the start. When excluding the outliers on the snowfield traps, a few fluctuations were visible in the nightly setup of the cross-window traps where moth occurrences peaked occasionally.

In the separate GLMs per trap type we found significant positive effects of sunny weather and soil temperature, as well as negative effects of wind speed on mean abundance (Table S1) for the pitfall traps. There was a significant positive effect of soil temperature on species richness. For the malaise trap system significant positive effects of air temperature on mean abundance could be observed. Furthermore, significant effects of air temperature and relative humidity, on species richness were observed. A significant positive effect of relative humidity on mean arthropod abundance for the cross-window traps was shown. There were also significant positive effects of date, air temperature, and lunar phase on species richness: during full moon we measured a peak in nocturnal lepidopteran captures. When testing the snowfield trap system, a significant effect of date, relative humidity, and wind direction (northness) on mean arthropod abundance could be detected. The effect of date was positive and significant on species richness for this collection method.

Community composition and method comparison

The arthropod community at the summit of Hoher Sonnblick was dominated by *Desoria saltans* (Isotomidae, Collembola) which was found at the snow patches on the slope beneath the observatory (Table S2). Nocturnal Lepidoptera (family Geometridae and Noctuidae; total 152 individuals) were frequently collected as well, though exclusively via the cross-window traps and capture rates were limited by low temperatures. Another frequent order were the dipterans (15 families) which were present in all traps. Pitfall traps captured a variety of insect orders such as other Collembola and Coleoptera. Here, the

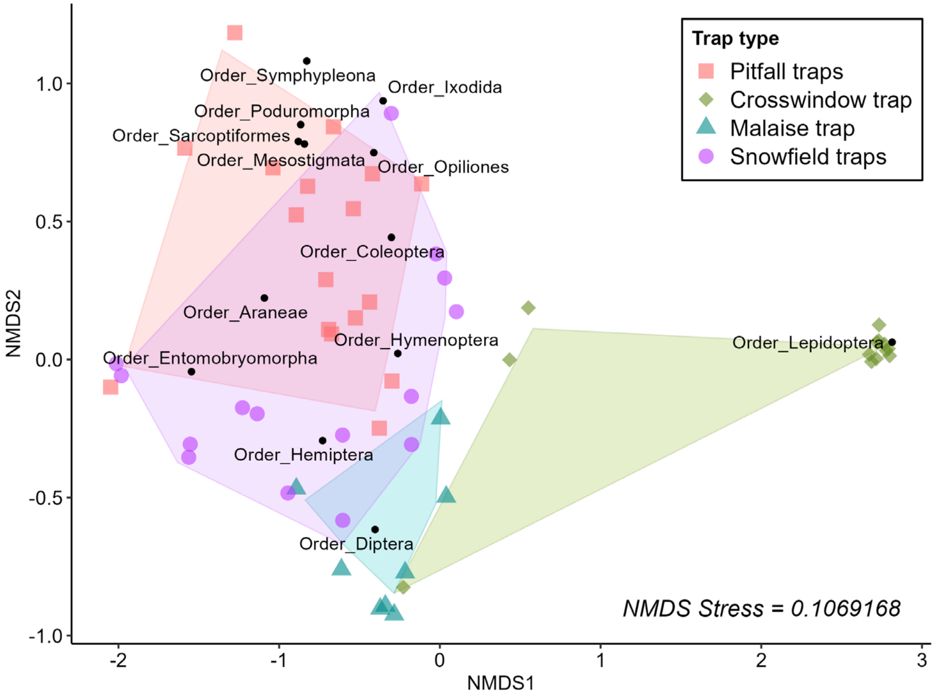

Fig. 5: Non-metric Multidimensional Scaling of the summit community on order level between the four different traps using the Bray-Curtis dissimilarity index. The symbols represent the insect order communities per trap type and sampling point (light orange squares = pitfall trap $_{n = 17}$, purple circles = snowfield traps $_{n = 15}$, turquoise triangle = malaise trap $_{n = 8}$, and green diamond = cross-window traps $_{n = 13}$). Differences in community composition are shown via distance between encircled areas. | **Abb. 5:** Nicht-metrische multidimensionale Skalierung der Gipfelgemeinschaft auf Ordnungsebene zwischen den vier verschiedenen Fallen mithilfe des Bray-Curtis-Dissimilaritätsindex. Die Symbole repräsentieren die Insektenordnungsgemeinschaften pro Fallentyp und Probenahmepunkt (hellorange Quadrate = Barberfallen $_{n = 17}$, violette Kreise = Schneefeldfallen $_{n = 15}$, türkisfarbene Dreiecke = Malaisefalle $_{n = 8}$ und grüne Raute = Kreuzfensterfallen $_{n = 13}$). Unterschiede in der Gemeinschaftszusammensetzung werden durch den Abstand zwischen den umrahmten Bereichen dargestellt.

alpine endemic *Orenoebria atrata* (Carabidae) was predominant. From the snowfield traps many bark beetles (Scolytidae) were gathered. The order Hymenoptera was the fourth most common order, represented by seven different families. In this study, mites were sometimes found still attached to their carabid hosts. Arachnids were found sparsely, yet two alpine specialists should be emphasized: *Erigone tirolensis* (Linyphiidae) and *Mitopus glacialis* (Phalangiidae).

Due to limited replicates and low sample sizes, arthropod community composition was analyzed at the order level. The effect of trap type (Fig. 5; $F_{3,35} = 6.1349$, $P < 0.001$) on community composition was highly significant. Different arthropod groups were collected by different trap types. Pitfall traps sampled a variety of orders, however, mostly ground-dwelling or pollinating arthropods. Malaise trap collected mostly dipterans. The cross-window system was most successful with moths. Snowfield traps were biased for glacier fleas (*Desoria saltans*, Collembola), but also a variety of arthropods were gathered.

Each system met limitations concerning extreme weather events and was not fully functional during all times. For instance, thunderstorms reduced the sampling days for the camera traps to eleven out of 28 days. Furthermore, only six out of these eleven offered reliable pictures without fog. Even after manual calibration before field work, the accurate interpretation of the results proved difficult with deterioration caused by rain, fog, or frost. Due to the unconvincing results, the camera method was excluded from further analysis. Other methods like the pitfall traps could not be sampled during fresh snow fall events, as they were covered with snow and therefore inaccessible.

Discussion

Our findings demonstrate that all measured environmental variables affected arthropod morphospecies richness and abundance in some way. July is generally characterized by relatively stable environmental conditions at „Hoher Sonnblick", however, during the sampling period of 2023 a bad weather period befell Central Europe. Environmental parameters significantly influenced arthropod catches: soil temperature and wind speed affected the composition of species collected by pitfall traps; humidity increased abundance of arthropods in cross-window traps; and air temperature influenced species richness in the collections. Humidity was a key driver for *D. saltans* abundance on glacial snowfields. Similar patterns were observed in other studies (Knop et al. 2023; Sandeep et al. 2023).

Snowfield traps primarily yielded small and surface-adapted species like *Desoria saltans* and Linyphiid spiders, including *Erigone tirolensis*, or wind-dispersed insects like Scolytidae. *D. saltans* exhibited swarming behaviour after snowfall periods. Therefore, a substantial short-term increase—up to tenfold—of observable individuals could be sampled on two sampling days via snowfield traps analysis. Such mass occurrences of Collembola, including *Ceratophysella sigillata*, *Hypogastrura socialis*, and *Isotoma hiemalis*, are well-documented (Christian & Meyer 1997) and typically occur in late spring, coinciding with hatching and molting events. Molting of *D. saltans* was observed during this period in our study as well. However, as earlier studies suggest that the abundant occurrence of Collembola (Agustí et al. 2003; Somme 1989; Singer 2016) may be associated with snowmelt and surface conditions (Heiniger 1989), hence resulting in an aggregation of *Desoria saltans* on the snow surface (Kopeski 1988).

Similar fluctuations, albeit less extreme, were recorded in other methods. As cross-window traps varied in function – ethanol-based by day, UV-attractant by night – the net setup may have allowed escape. Migratory events of lepidopterans could not be confirmed; however, the moth *Autographa gamma* was frequently caught in the cross-window trap, especially during full moon nights. These observations are consistent with previous findings that lunar phase influences nocturnal insect activity (Nowinszky & Puskás 2017), though usually highest number of caught individuals would be expected during new moon or periods of fog when UV sources increase likelihood of captures, and light source type was singled out in earlier studies as a main driver for lepidopteran catches (Nowinszky & Puskás 2017; Baker & Sadovy 1978). Migratory events for Gamma moths (Hofer 2009) and other insects (Ruczyński et al. 2020) have been observed at mountain passages in adjacent valleys in late summer (Mazzucco 1975). Some insectivorous predators have specialised on these mass occurrences (Ruczyński et al. 2020).

In our study, primarily Coleoptera, Collembola, Diptera, and Arachnida were found, including the flightless Carabid *Oreonebria atrata*, and the glacier harvestman *Mitopus glacialis*. These endemic species were commonly found in other studies as well (Rabitsch & Essl 2009; Komposch & Gruber 2004). Covers likely increased efficiency by shielding from precipitation, however, Litavský & Prokop (2024) discussed the possibility of reduced accessibility. Malaise traps remained functional under alpine extremes and sampled Diptera, Hymenoptera, and occasional Entomobryomorpha (Collembola) during snowmelt, even though, the entry could have been blocked by snow during extreme weather events. Abundance was indeed lower during snow fall events, likely also caused by effects of the adverse conditions on insect movement. All trap types exhibited specific advantages and limitations, often influenced by environmental conditions. Camera traps, though potentially effective, are constrained by humidity. Snowfield traps proved vulnerable to being completely covered, while pitfall traps could serve as a more robust alternative for collecting Collembola under unstable environmental conditions. For cross-window traps, increasing trap numbers may enhance moth sampling. The combined use of multiple trap types enabled broader arthropod sampling. Extending sampling durations and increasing replicate numbers would improve the basis for this high-altitude site and for statistical reliability.

Future improvements could include more detailed vegetation surveys in order to link arthropod communities to vegetation properties and plant species. A comparative study along altitudinal gradients would be essential to understand shifts of alpine arthropod communities with climate change and possibly predict future communities at „Hoher Sonnblick". Less invasive methods, such as environmental DNA analysis via flower washing could reduce biomass removal and its ecological impacts. Arthropod lifecycle dynamics are significantly influenced by environmental parameters, with temperature identified as the primary driver of abundance. In the mountainous regions containing ice-free sanctuaries specialists evolved following orographic isolation (GLORIA programme 2024), which decreases chances of recolonization (Wittig & Niekisch 2014). Alpine species have been affected by the rapid increase in temperature and therefore must adapt or might become extinct soon. However, due to many technical and methodological challenges, alpine habitats are understudied. Studying alpine ecosystems is critical for informing responses to climate-driven ecological changes, which is why now is the best time to study this special ecosystem.

Acknowledgements

We would like to thank Mag. Karin Widerin for co-supervising this study and for support in networking and implementation of the project. Moreover, we are grateful to Dr. Elke Ludewig and her team at the Sonnblick Observatory for technical assistance and financial support during field work. We would also like to thank the arthropod specialists, who helped with species identification, namely Helge Heimburg of Graz University (Syrphids: *Scaeva* *pyrasti*-individuals), as well as Tobias Seifert (Coleoptera) and Johannes R. Schall (Arachnids) of Paris-Lodron-University Salzburg. We sincerely appreciate all valuable comments and suggestions by the reviewers, which helped to improve the quality of the manuscript.

Electronic Supplement

Tab. S1: Results of the generalized linear model testing the effect of the environmental variables on arthropod abundance or arthropod morphospecies richness for each trap type separately. | **Tab. S1:** Ergebnisse des generalisierten linearen Modells für jeden Fallentyp.

Tab. S2: Summary of arthropod abundances and morphospecies richness per trap type | **Tab. S2:** Zusammenfassung der mit unterschiedlichen methodischen Ansätzen gesammelten Arthropoden.

Tab. S3: List of collected individuals – determined to at least Genera level and if possible, the species was identified. | **Tab. S3:** Liste der gesammelten Individuen mit Bestimmung auf Gattungsniveau, falls möglich wurde bis auf Artniveau bestimmt.

https://www.zobodat.at/pdf/supp/Wagner_Petermann_Supplement.pdf

References

Agustí N, Shayler SP, Harwood JD, Vaughan IP, Sunderland KD, Symondson WOC (2003) Collembola as alternative prey sustaining spiders in arable ecosystems: prey detection within predators using molecular markers. Molecular ecology 12(12), 3467–3475 (https://doi.org/10.1046/j.1365-294X.2003.02014.x)

Baker RR, Sadovy Y (1978) The distance and nature of the light-trap response of moths. Nature 276(5690), 818–821 (https://doi.org/10.1038/276818a0)

Begon M, Howarth RW, Townsend CR (2017) Ökologie. Springer Spektrum, Berlin, Heidelberg 599 pp. (ISBN 978-3-662-49905-4)

Böhme J, Freude H, Harde KW, Klausnitzer B, Koch KC, Lohse GA et al. (1983) Die Käfer Mitteleuropas. Band 2: Adephaga I: Carabidae. Spektrum Akademischer Verlag, Heidelberg 521 pp. (ISBN 978-3-8274-1551-6)

Breckle SW, Rafiqpoor MD (2019) Vegetation und Klima. Springer Spektrum, Berlin, Heidelberg 462 pp. (ISBN 978-3-662-59898-6)

Carson R (2021) Der stumme Frühling. CH Beck, München 144 pp. (ISBN 978-3-4065-4760-7)

Christian E, Meyer E (1997) Ein spektakuläres Massenauftreten von Springschwänzen in Tirol, Österreich (Insecta, Collembola: Ceratophysella sigillata). Berichte des naturwissenschaftlichen-medizinischen Verein Innsbruck 84, 315–320

Dietz C, Kiefer A (2024) Naturführer Fledermäuse Europas. Alle Arten erkennen und sicher bestimmen. Franckh-Kosmos Verlag, Stuttgart 416 pp. (ISBN 978-3-440-16754-0)

Ernakovich JG, Hopping KA, Berdanier AB, Simpson RT, Kachergis EJ, Steltzer H, Wallenstein MD (2014) Predicted responses of arctic and alpine ecosystems to altered seasonality under climate change. Global Change Biology 20(10), 3256–69 (https://doi.org/10.1111/gcb.12568)

GLORIA programme (2024): Background. Mountain regions – hot spots of organismic diversity. GLORIA https://www.gloria.ac.at/scope/background (accessed: 13–6–2024)

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren T, Goulson D, Kroon Hd (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PloS ONE 12(10) (https://doi.org/10.1371/journal.pone.0185809)

Heiniger PH (1989) Arthropoden auf Schneefeldern und in schneefreien Habitaten im Jungfraugebiet (Berner Oberland, Schweiz). Mitteilungen der Schweizerischen Entomologischen Gesellschaft 62, 375–386 (http://doi.org/10.5169/seals-402367)

Henry SC, McQuillan PB, Kirkpatrick JB (2018) An Alpine Malaise trap. Alpine Entomology 2(1), 51–58 (https://doi.org/10.3897/alpento.2.24800)

Hofer R (Ed.) (2009): Die Alpen. Einblicke in die Natur. Innsbruck: Innsbruck Univ. Press, Innsbruck 160 pp. (ISBN 978-3-902719-02-7)

Jandl R, Tappeiner U, Foldal CB, Erb KH (Eds.) (2024) APCC Special Report: Landnutzung und Klimawandel in Österreich. Springer Spektrum, Berlin 528 pp. (ISBN 978-3-662-67863-3)

Kareiva P, Marvier M (2015) Conservation Science: Balancing the Needs of People and Nature. Macmillan Learning, New York 642 pp. (ISBN 9781319146719)

Kerner JM, Krauss J, Maihoff F, Bofinger L, Classen A (2023) Alpine butterflies want to fly high: Species and communities shift upwards faster than their host plants. Ecology 104(1), 1–17 (https://doi.org/10.1002/ecy.3848)

Knop E, Grimm ML, Korner-Nievergelt F, Schmid B, Liechti F (2023) Patterns of high-flying insect abundance are shaped by landscape type and abiotic conditions. Scientific reports 13(1), 15114 (https://doi.org/10.1038/s41598-023-42212-z)

Ko GH, Park DY, Lee JW (2018) Taxonomic review of subfamily Pteromalinae (Hymenoptera, Chalcidoidea) with 25 newly recorded species in South Korea. Journal of Asia-Pacific Biodiversity 11(1), 87–122 (https://doi.org/10.1016/j.japb.2017.08.006)

Komposch C, Gruber J (2004) Die Weberknechte Österreichs. (Arachnida, Opiliones). Denisia 12, Kataloge der OÖ Landesmuseen 14, 485–534

Kopeszki H (1988) Zur Biologie zweier hochalpiner Collembolen – *Isotomurus palliceps* (UZEL, 1891) und *Isotoma saltans* (NICOLET, 1841), Zool. Jb. Syst.115 (4), 405–439

Lee RE, Denlinger DL (1991) Insects at low temperature. Springer, New York 514 pp. (ISBN 978-1-4757-0192-0)

Litavský J, Prokop P (2024) Coverings on Pitfall Traps Influence the Abundance of Ground-Dwelling Arthropods. Diversity 16(1), 19 (https://doi.org/10.3390/d16010019)

Lompe A (2017): Die Käfer Europas. Ein Bestimmungswerk im Internet. https://coleonet.de/coleo/index.htm (accessed: 17-6-2024)

Ludewig E, Senoner W, Adler S, Aigner L, Baumann-Stanzer K, Beres N, Binder D, Bittner M, Boch R, Bocker M, Bogert P, Burkart J, Butschek M, Buxbaum I, Čupr P, Daxbacher M, Daxbacher N, Degrendele C, Delleske R, … Wüst S (2023) Sonnblick Observatorium 2023. Wissenschaftliche Aktivitäten. GeoSphere Austria, Wien, 1–80, https://www.sonnblick.net/ic-orig/yDQyfCGr/InhalteBroschueren/SBO_Broschuere-Brochure_2023_FINAL2www.pdf (accessed: 6–10–2024)

Mandl K, Schönmann R (1978) Catalogus Faunae Austriae. Teil XV b: Coleoptera, Carabidae II. Verlag der Österreichischen Akademie der Wissenschaften, Wien 1–16

Mazzucco K (1975) Migration der Lepidopteren in den Hohen Tauern. Dissertation zur Erlangung des Doktorgrades an der Philosophischen Fakultät der Universität Salzburg. Salzburg, 1–95

Mertz P (2008) Alpenpflanzen in ihren Lebensräumen. Ein Bestimmungsbuch. Haupt Verlag, Bern 480 pp. (ISBN 978-3258071954)

Mertz P (2017) Alpenpflanzen in ihren Lebensräumen. Ein Bestimmungsbuch. Haupt Natur, Bern 480 pp. (ISBN 978-3-258-08005-5)

Müller HJ, Bährmann R (2022) Bestimmung wirbelloser Tiere. Bildtafeln für zoologische Bestimmungsübungen und Exkursionen. Springer Spektrum, Berlin 427 pp. (ISBN 978-3-662-61716-8)

Müller-Motzfeld G (2012) Die Käfer Mitteleuropas – Adephaga 1: Carabidae (Laufkäfer). Spektrum Akademischer Verlag, Heidelberg 521 pp. (ISBN 978-3-8274-1551-6)

Nagy L (2003) Alpine biodiversity in Europe. Springer Berlin, Heidelberg 479 pp. (ISBN 978-3-642-62387-5)

Nationalpark Hohe Tauern (2024): Der Nationalpark in Zahlen – Nationalpark Hohe Tauern. https://hohetauern.at/de/natur/nationalpark.html (accessed: 10–6–2024)

Nowinszky L, Puskas J (2017) Light-Trap Catch of Insects in Connection with Environmental Factors. In: Shields VDC (ed.) (2017) Biological Control of Pest and Vector Insects, InTech 360 pp. (https://doi.org/10.5772/66251)

Observation International (2023): ObsIdentify. Version Version 3.15. Observation.org.

QGIS Development Team (2024) QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

Rabitsch W, Essl F (2009) Endemiten. Kostbarkeiten aus Österreichs Pflanzen- und Tierwelt. Naturwissenschaftlicher Verein für Kärnten, Klagenfurt & Umweltbundesamt GmbH, Wien 832 pp. (ISBN 978-3-85328-049-2)

R Core Team (2022) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. https://www.R-project.org

Reverté S, Retana J, Gómez JM, Bosch J (2016) Pollinators show flower colour preferences but flowers with similar colours do not attract similar pollinators. Annals of botany 118(2), 249–257 (https://doi.org/10.1093/aob/mcw103)

Ruczyński I, Hałat Z, Zegarek M, Borowik T, Dechmann DKN (2020) Camera transects as a method to monitor high temporal and spatial ephemerality of flying nocturnal insects. Methods in Ecology and Evolution 11(2), 294–302 (https://doi.org/10.1111/2041-210X.13339)

Sandeep K, Singh MK, Shashank DU (2023) Causes of Insect Abundance. Vigyan Varta 4(6), 209–212

Schaefer M (Ed.) (2018) Brohmer: Fauna von Deutschland. Ein Bestimmungsbuch unserer heimischen Tierwelt. Quelle & Meyer, Wiebelsheim 776 pp. (ISBN 978-3494017600)

Schedl KE (1980) Catalogus Faunae Austriae. Teil XV y: Coleoptera, Fa. Scolytidae und Platypodidae. Verlag der Österreichischen Akademie der Wissenschaften, Wien 39 pp.

Settele J (2020) Die Triple-Krise: Artensterben, Klimawandel, Pandemien. Warum wir dringend handeln müssen. Edel Books, Hamburg 320 pp. (ISBN 978-3-8419-0653-3)

Sheikh AH, Thomas M, Bhandari R, Bunkar K (2016) Light trap and insect sampling: an overview. International Journal of Current Research 8(11), 40868–40873

Singer F (2016) Ecology in action. Cambridge University Press, Cambridge 643 pp. (ISBN 9781108927222)

Somme L (1989) Adaptations of Terrestrial Arthropods to the Alpine Environment. Biological Reviews 64(4), 367–407 (https://doi.org/10.1111/j.1469-185X.1989.tb00681.x)

Ssymank A, Sorg M, Doczkal D, Rulik B, Merkel-Wallner G, Vischer-Leopold M (2018) Praktische Hinweise und Empfehlungen zur Anwendung von Malaisefallen für Insekten in der Biodiversitätserfassung und im Monitoring. Series Naturalis 1, 1–12

Streitberger M, Ackermann W, Fartmann T, Kriegel G, Ruff A, Balzer S, Nehring S (2016) Artenschutz unter Klimawandel: Perspektiven für ein zukunftsfähiges Handlungskonzept. Bundesamt für Naturschutz, Bonn-Bad Godesberg, Münster 368 pp. (ISBN 978-3-7843-4047-0)

Stüber E (1989): Der österreichische Naturführer in Farbe. Pinguin, Innsbruck 496 pp. (ISBN 978-3701622993)

Wittig R, Niekisch M (2014) Biodiversität: Grundlagen, Gefährdung, Schutz. Springer Spektrum Berlin, Heidelberg 585 pp. (ISBN 978-3-642-54693-8)