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NIDAL FETNASSI

Determinants of moth assemblages across human-modified landscapes of Estonia and Morocco

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Press

Department of Zoology, Institute of Ecology and Earth Sciences Faculty of Science and Technology, University of Tartu, Estonia

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LIST OF ORIGINAL PUBLICATIONS

This thesis is the summary of the following papers, which are referred to in the thesis by their Roman numerals **I–IV**

I. **Fetnassi**, **N**., Ude, K., Kull, A., & Tammaru, T. (2022). Weather sensitivity of sugar bait trapping of nocturnal moths: A case study from northern Europe. *Insects*, 13(12), 1087. https://doi.org/10.3390/insects13121087

II. Ude, K., Foerster, S. I. A., **Fetnassi, N**., & Tammaru, T. (2025). Forest clear-cuts support diverse moth fauna but lack common grassland species. *Journal of Applied Ecology*, 62(6), 1473–1486. https://doi.org/10.1111/1365-2664.70063

III. **Fetnassi, N**., Foerster, S. I. A., Õunap, E., Ghamizi, M., & Tammaru, T. (2025). Complementary roles of agricultural and natural habitats in supporting moth diversity in semi-arid landscapes of Morocco. *European Journal of Entomology*, 122, 173–183. https://doi.org/10.14411/eje.2025.022

IV. **Fetnassi, N**., Õunap, E., Ghamizi, M., & Tammaru, T. Sustaining moth diversity in semi-arid landscapes of Morocco: the role of traditional irrigated agroecosystems. *Manuscript*

Author's contribution to the studies (*moderate contribution, **high contribution; ***leading role)

	I	**II**	**III**	**IV**
Original idea			**	***
Study design	*	*	***	***
Data collection		**	***	***
Data management and analysis	***	**	***	***
Manuscript preparation	***	*	***	***

1. INTRODUCTION

1.1. Anthropogenic activities and their impact on biodiversity

Human activities have emerged as a dominant force reshaping the Earth's natural systems, exerting unprecedented and often irreversible pressures on landscapes and ecosystems (Strassburg et al., 2014; Chu & Karr, 2017). Key anthropogenic factors driving these environmental pressures are land-use change, pollution, habitat fragmentation, and the introduction of invasive species (Stendera et al., 2012; Caro et al., 2022). A prominent example of these pressures is the large-scale conversion of natural habitats for human purposes.

Large-scale land conversion for agriculture now accounts for nearly 44% of the world's habitable land, approximately 548 million square kilometers to meet the growing demand for food (Godfray et al., 2010; Ritchie & Roser, 2020). Additionally, urban expansion driven by population growth—over half of the world's population now resides in cities (Ritchie et al., 2024)—has transformed extensive areas of forests, grasslands, and wetlands. This expansion contributes not only to widespread habitat loss, but also to fragmentation, increased light and air pollution, and the urban heat island effect, which arises from the replacement of green areas and natural habitats with buildings and intensively managed lawns (Sanetra et al., 2024). When these pressures interact with the accelerating impacts of climate change, the vulnerability of natural ecosystems is further magnified, resulting in rapid decline in biodiversity (Dobson et al., 2021; Prakash & Verma, 2022).

Nearly a third of the Earth's land surface is covered by forests, which support the majority of terrestrial biodiversity and play a vital role in regulating global ecological processes (FAO & UNEP, 2020). Growing demands for timber and other forest products have intensified forest management all over the world (Birdsey & Pan, 2015). In northern Europe, even-aged silvicultural systems, particularly clear-cutting, are common forest management practices that have significantly modified forest habitats (Aszalós et al., 2022). These practices cause sudden disturbances in the natural succession of forest vegetation and alter tree canopy closure (Tonteri et al., 2016).

Habitat fragmentation has also triggered significant changes in community composition, with some species experiencing sudden population outbreaks, while others have become increasingly rare or vulnerable to extinction (Schowalter, 2012; Pardini et al., 2017). Such shifts disrupt species interactions (Lewis et al., 2021), alter food web dynamics (Strong & Frank, 2010) leading thus, to overall ecosystem disequilibrium. For example, in boreal forests, clear-cutting often results in substantial declines in insect diversity, particularly affecting saproxylic and ground-dwelling species that rely on dead wood or are adapted to late-successional habitats (Johansson et al., 2007; Toivanen & Kotiaho, 2007; Stenbacka et al., 2010). Similar patterns occur in other temperate forests, where intensive forestry reduces the diversity of herbivorous moths (Summerville, 2011; Summerville & Marquis, 2017) and shifts community composition (Thorn et al., 2015). These impacts are often driven by the decline of forest specialist species, which are particularly vulnerable to habitat loss (Summerville & Crist, 2002). Pesticides used in intensive agriculture can harm various insect pollinators and may drive population decline (Guzman et al., 2024). Additionally, they may also alter species populations in opposing ways—for instance, some generalist or disturbance-tolerant species may increase while sensitive or specialist species decline—and when persistent, they usually shift community structure toward reduced ecosystem functionality (Bartomeus et al., 2013; Sánchez-Bayo, 2021). Moreover, the use of synthetic fertilizers have been shown to lower plant resistance to insect pests, often boosting pest populations and thereby increasing reliance on insecticides (Yardim & Edwards, 2003). In extreme urban environment, light pollution arises as another treat to nocturnal biodiversity (Hölker et al., 2010). Light pollution disrupts natural light–dark cycles, with cascading effects on nocturnal species that include impaired navigation, altered predator–prey dynamics, reduced foraging efficiency, and declines in reproduction and population stability (Karan et al., 2023).

1.2. Sustainable practices transform human activities into forces for ecological balance

Some forms of human activities can also be beneficial to biodiversity (Babu, 2023). Several novel landscapes are increasingly acknowledged as valuable substitutes for declining natural and semi-natural habitats, since they can function as refuges (Johansen et al., 2022; Rajpar et al., 2022). Studies have shown that managed forests—including clear-cut areas—as well as linear habitats such as road verges, power-line corridors, and railway corridors can serve as novel habitats for insects that are typically associated with declining semi-natural grasslands (Berg et al., 2011; Viljur & Teder, 2016).

For instance, by opening the canopy, clearcutting increases light availability and alters microclimatic conditions, which promotes the growth of early-successional plants such as grasses, shrubs, and pioneer tree species (Keenan & Kimmins, 1993; Swanson et al., 2011). These plant communities provide resources and shelter for a variety of wildlife, including insects, birds, and mammals (Bogdziewicz & Zwolak, 2014; Ram et al., 2020; Milberg et al., 2021). In some forest types, especially boreal systems, clearcutting can mimic natural disturbances such as wildfire, helping to maintain landscape-level heterogeneity and supporting species that depend on young, open habitats (Franklin et al., 1997; Chaundy-Smart et al., 2012). Railroad embankments have also been suggested to enhance bird species richness and diversity and, by supporting other organisms notably insects, can increase habitat heterogeneity and conservation value (Kajzer-Bonk et al., 2019). Similarly, powerline strips have been shown to support diverse bee communities, including parasitic and cavity-nesting species, and—with proper management—could provide millions of acres of bee-friendly habitat to help offset pollination losses from declining honeybee populations (Russell et al., 2005).

In agro-ecosystems, road verges and hedges, can be vital habitats for insect by providing a higher plant diversity than in fields, if managed appropriately (Phillips et al., 2019). Sustainable farming methods can reduce environmental damage while maintaining healthy food and animals (Gamage et al., 2023; Sharma et al., 2024). Unlike intensive monocultures, crop diversity creates more heterogeneous landscapes that support a wider range of insect species (Aizen et al., 2019; Jankielsohn, 2023 and references there in). Organic farming promotes soil microbial diversity and reduces chemical stressors, fostering resilience and functional biodiversity across multiple trophic levels (Bengtsson et al., 2005). Similarly, agroforestry systems enhance soil fertility by supplying organic matter from shade tree litter (Moço et al., 2010; Isaac et al., 2024).

Urban ecosystems, despite being highly modified, can also serve as significant biodiversity refuges. For instance, green infrastructure—including parks, urban forests, community gardens, green roofs, and constructed wetlands—supports species richness, improves ecological connectivity, and creates stepping-stone habitats in fragmented landscapes (Aronson et al., 2017; Wang et al., 2024). Studies in European and North American cities have shown that urban green spaces can support remarkably high levels of plant and invertebrate diversity—sometimes exceeding that of surrounding rural areas—while urban rivers and restored wetlands provide important breeding habitats for amphibians and birds (Beninde et al., 2015; Alikhani et al., 2021).

1.3. The ecological importance of Lepidoptera highlights the need for effective sampling methods

Lepidoptera—comprising butterflies and moths—represent one of the most diverse groups of insects, with at least 160,000 catalogued species, with 90% of which being nocturnal moths (Pohl et al., 2019; Bowden et al., 2025). These insects are predominantly herbivorous, with their larvae relying heavily on plants as a food source (Kim & Choi, 2021 and references there in). In their adult stage, many species feed on nectar or fruits (Cunningham et al., 2004). Nocturnal moths play an important role in pollination, complementing butterflies and other insect groups that are active during the day. Together, they provide continuous pollination, which supports plant reproduction and maintains genetic diversity (Hattori et al., 2020; Kalpana et al., 2024). Moths, similarly to many other insects, form a crucial link in terrestrial food webs, serving as prey for birds, bats and predatory insects, while also hosting defensive symbiotic microorganisms, which further influence ecosystem interactions (Hooks et al., 2003; Voirol et al., 2018; Kolkert et al., 2020). They serve as sensitive bioindicators, with population outbreaks, decline and changes in community structure often signaling habitat change or the impacts of climate change (Dar & Jamal, 2021). For instance, as a response to various forms of habitat fragmentation, generalist species are often favored because of their broader ecological tolerance and flexible resource use, while habitat specialists decline due to their stricter environmental requirements (Ramiadantsoa et al., 2018; Narango et al., 2025), leading to shifts in community dynamics (Uhl et al., 2021). Moths are also sensitive indicators of climate change: many species adapted to cold have been documented to shift their ranges to higher latitudes and altitudes, as a response to rising temperatures (Keret et al., 2020; Kwon et al., 2024).

Due to this diversity of roles, systematic sampling of nocturnal Lepidoptera is essential in various contexts, including faunistic research (Murillo-Ramos et al., 2021), environmental monitoring (Franzén & Johannesson, 2007; Bell et al., 2020), and agricultural pest management (Choi et al., 2011; Yao et al., 2012). Many methods for sampling Lepidoptera have been developed, among which light trapping is the most common in quantitative studies on moths (Raimondo et al., 2004; Brehm, 2017). This method relies on the attraction of moths to artificial light sources, which often emit ultraviolet (UV) wavelengths that are highly attractive to these nocturnal insects (Infusino et al., 2017). In their natural environment, moths are attracted to sources of UV light such as moonlight and reflected sunlight (Juddin et al., 2023). Artificial lights that emit UV rays can thus replicate this natural attraction, making them particularly effective for capturing moths (Brehm et al., 2021). However, this method can produce biased results not only because it depends on environmental lighting conditions, but also fundamentally because different species are attracted to lights to varying degrees (Van Langevelde et al., 2011).

For example, in high latitude summers, traps are more effective in dark forest environments than in open landscapes which may introduce systematic error to landscape-ecological studies. In addition, the effectiveness of light trapping depends on moonlight and cloud cover (Fayle et al., 2007; Bjerge et al., 2021), which makes it necessary to adopt alternative sampling methods. One of such alternative possibilities is the use of sugar-bait traps. Sugar baiting takes advantage of the natural feeding behavior of adult moths by attracting individuals that actively consume food (nectar, fermenting fruit etc.) (Freitas et al., 2014). These traps typically use nutrient-rich sugar mixtures designed to mimic the moths' natural diet. The composition of sugar baits can vary, but they are commonly prepared using combinations such as sugar with red wine, sugar with beer, or fermented fruits, a method also applied in butterfly studies (Yela & Holyoak, 1997; Sussenbach & Fiedler, 1999; Pettersson & Franzén, 2008; Silva et al., 2020).

Nevertheless, ecological studies employing bait trapping are relatively scarce compared to those using light traps. When applied, bait traps are often combined with light trapping in order to capture a broader spectrum of the lepidopteran fauna (e.g. Franzén & Johannesson, 2007; Merckx et al., 2018). Since light traps have been extensively used, their efficiency has been assessed in numerous studies. For instance, studies have shown that the abundance and diversity of moths captured in light traps are strongly influenced by a variety of factors (Fayle et al., 2007). These include the type and color of the light source (Infusino et al., 2017;

Ardeh et al., 2021), as well as weather conditions such as temperature, wind speed, humidity, and cloud cover (Yela & Holyoak, 1997; Jonason et al., 2014; Niermann & Brehm, 2022).

1.4. Aims and objectives

Unlike light traps, which have been extensively studied, the potential of bait trapping as a method in ecological studies and respective limitations remain poorly understood, particularly under variable environmental conditions. One of the aims of this thesis is therefore to assess the value of sugar-bait trapping as a research method and to provide guidance for interpreting respective results in ecological monitoring. To address this objective, we analyzed the influence of different weather parameters on moth trap catches. Specifically, we examined how factors such as temperature, humidity, wind speed, and precipitation affected three key metrics of moth assemblages: overall abundance, species richness, and diversity. By disentangling the relationship between weather variability and trapping outcomes, we aimed to evaluate the reliability of bait trapping under different environmental conditions and to identify potential biases that may affect ecological interpretations **(I).**

Building on this methodological foundation, the thesis further seeks to examine how human activities shape moth diversity and community structure across managed habitats. In the first case study of this type **(II)**, we focused on clear-cuts as an example of novel habitat in production forests in the hemiboreal region of northern Europe. Specifically, we sought to evaluate the suitability of clear-cut sites as habitats for moths, with a particular emphasis on species typically associated with semi-natural grasslands. Our goal was to understand how moth diversity and community structure are shaped by time since clear-cutting (early successional age stands from one to 6 years old) and by the regeneration method applied (natural vs. artificial).

Although Lepidoptera are ecologically significant in almost all terrestrial habitats, research on these animals remains unevenly distributed across the globe. Regions such as Europe, North America, and parts of Asia have been relatively well studied (Choi & An, 2013; Ashton et al., 2016; Valtonen et al., 2017; Hill et al., 2021; Belitz et al., 2024; Maes et al., 2024), whereas areas like North Africa remain poorly investigated. The paucity of faunistic and ecological data in these regions restricts our understanding of the ecological role of Lepidoptera, functional diversity, and responses to environmental change, thereby hindering the development of effective conservation strategies. Against this background, studies **III** and **IV** focused on examining the ecological factors shaping moth community composition in Morocco's semi-arid landscapes. These studies were carried out in agricultural areas maintained using traditional irrigation practices, representing an example of managed habitats during the dry season.

Study **III** specifically aimed at analyzing moth communities across a gradient of human impact comparing three habitat types—forest, riverbanks to olive groves.

Study **IV** addressed similar questions but focused more precisely on how the proportion of different land use types (natural, herbaceous field crops, orchards, fallow lands and build-up areas) affect the community parameters of moths. Studies **II**, **III**, and **IV** discuss the results within the framework of conservation biology, evaluating whether the studied anthropogenic habitats can serve as alternative refuges for species whose natural habitats are increasingly threatened by land-use change and climate change.

This thesis includes studies conducted in two contrasting regions: Estonia and Morocco. Although the research does not aim to provide a direct comparison between the two areas, working in both regions offered valuable opportunities to explore how different forms of human activity shape moth diversity under distinct environmental conditions. In Estonia, human activity is primarily expressed through forest management practices, whereas in Morocco, it is reflected in traditional irrigated agricultural systems within a semi-arid landscape. Examining moth assemblages across these two settings allowed for a broader understanding of how human land use affects biodiversity, revealing both context-specific responses and general patterns that transcend regional differences.

2. MATERIAL AND METHODS

2.1. Study areas and sites

Studies **I** and **II** were conducted in southern Estonia representing the hemiboreal mixed forests zone (Barbati et al., 2006). Specifically, study **I** analyzed the dependence of bait trap catches on weather parameters. Sampling was performed near the city of Tartu (58°23′ N, 26°43′ E), in four clear-cuts of 3–4 years-old (~2 ha each) embedded in mixed forests dominated by *Picea abies, Pinus sylvestris, Betula* spp., *Populus tremula*, and *Alnus incana*. The clear-cuts were characterized by herbaceous vegetation (0.5–1.5 m tall), regenerating saplings, and patches of dense stands of *Rubus idaeus*. Study **II** evaluated the suitability of clear-cut areas as habitats for nocturnal moths, encompassing 50 clear-cuts (2–6 years old) situated within the *Aegopodium* site-type forests according to the classification of Lõhmus (2004). The study sites were distributed across a ~70 × 90 km area, representing both artificial and natural regeneration (Fig. 1). Forests vegetation included a mixed tree layer with the same dominant species as in study **I** (though *Pinus sylvestris* was less frequent), along with diverse shrub and herb layers. For reference, three pairs of mature forest plots and adjacent meadows were also surveyed.

Studies **III** and **IV**, conducted in the central High Atlas Mountains of Morocco, and examined the effects of land use on moth assemblages. The study area is characterized by rugged terrain with steep slopes, valleys, and high plateaus (Fig. 2), with a semi-arid to arid climate marked by a wet season (October–May) and a dry season (June–September) (Bouamri et al., 2018). Our study area encompassed nine villages across two river sub-basins, including natural, semi-natural, agricultural, and (in study **IV**) residential areas (Fig. 3). Study **III** was conducted in the Zat sub-basin (eight villages). The landscape consisted mainly of juniper shrublands, oak stands, and riparian zones dominated by *Populus alba* and *Salix pedicellata* (Mostakim et al., 2022b). Agricultural land included olive groves (≥3 ha) intercropped with seasonal crops such as alfalfa, lemon verbena, and corn. Study **IV** was carried out in one village in the Ghdat sub-basin, Taddart (31°28' N, 7°20' W), where land use was dominated by agriculture (~84% of the valley) interspersed with patches of semi-natural vegetation. *Pinus halepensis* forests occupied the hillsides, while riparian areas hosted the same dominant species as in study **III**. Crops included alfalfa, clover, barley, peas, vegetables, corn, and perennial fruit trees (apple, almond, fig, walnut). Traditional seguia-based irrigation diverted water from rivers or mountain springs, providing a reliable water supply for field crops during the dry season (studies **III** and **IV**).

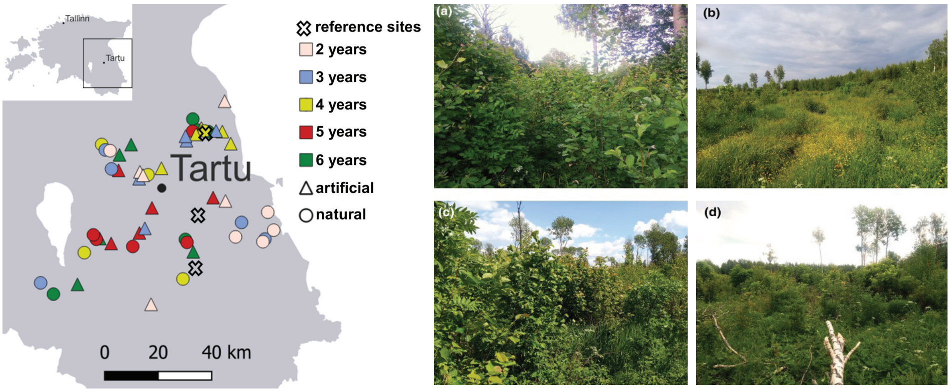

Fig. 1: Location of the clear-cuts and reference sites (meadow and forests) of study **II** (left side). The images on the right provide examples of clear-cuts under different regeneration regimes and of different age classes: (a) a 3-year-old clear-cut undergoing natural regeneration; (b) a 3-year-old clear-cut undergoing artificial regeneration; (c) a 6-year-old clear-cut undergoing natural regeneration; (d) a 6-year-old clear-cut undergoing artificial regeneration. The photos are taken in southern Estonia in June 2024. (Source: Study **II**).

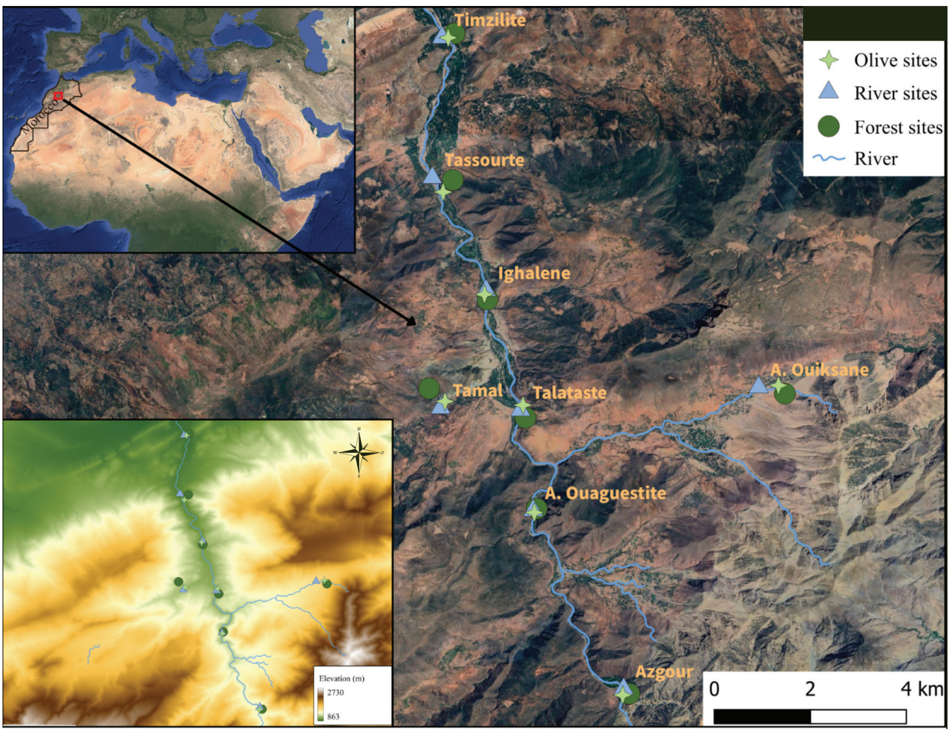

Fig. 2: Map of the study localities (eight villages) in the central High Atlas Mountains of Morocco of study. (Source: Study **III**).

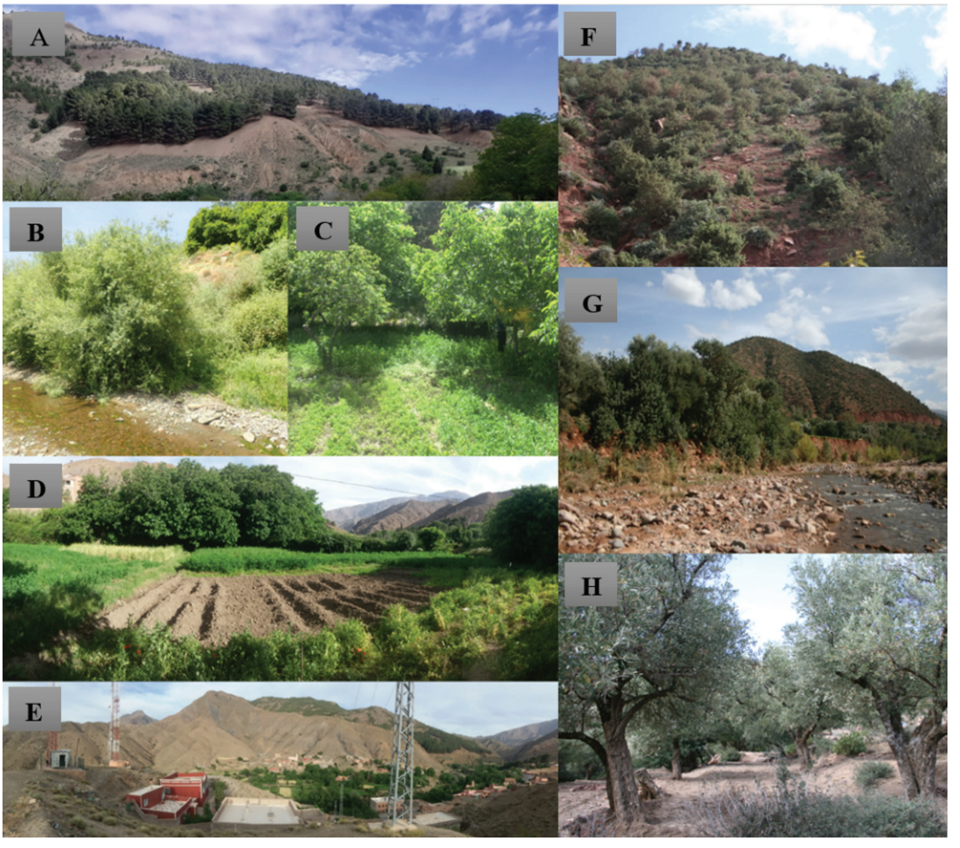

Fig. 3: A–E: Examples of land use types in Taddart village. (A–B) Natural vegetation, including Aleppo pine forests and riparian vegetation; (C) A walnut orchard; (D) A mixed-use field featuring barley, alfalfa, walnut trees, and fallow land and (E); Residential areas, characterized by buildings and electric towers (**IV**). F–H: Examples of habitat types studied in the Zat valley represented by the eight villages (Fetnassi et al., 2025). (F) Natural habitat represented by heterogeneous forests; (D) Semi-natural habitat represented by riverbanks and (F) olive groves. (Source: Study **III**).

2.2. Field methods

Nocturnal moths were sampled in all studies using automatic sugar bait traps. Traps (Tibiale insect equipment, Helsinki) consisted of a foldable conical plastic funnel with a circular roof, leading to a container with ethyl acetate as a killing agent (Laaksonen et al., 2006) (Fig. 4). The bait consisted of a sponge placed in a plastic cup and soaked in sugar dissolved in beer for the studies conducted in Estonia **(I** and **II)** and in red wine for those conducted in Morocco **(III** and **IV**).

In study **I**, conducted from 13 July to 2 September 2021, we investigated the dependence of bait catches on weather parameters. Five traps per clear-cut (20 study sites in total) were placed about 100 m apart in topographically diverse locations, which remained fixed throughout the study. Each trap was suspended from a rope between a retention tree and a 1.5 m metal pole, avoiding dense vegetation within 2 m. Weather stations (Vantage Vue Wireless, Davis Instruments Corporation, Hayward, CA, USA) mounted on the poles recorded 10 parameters every 10 minutes; averages or sums of 10 weather parameters were calculated for sunset-to-sunrise or sunset-to-midnight periods for analyses (Fig. 4).

In study **II**, the suitability of clear-cuts as habitats for nocturnal moths was evaluated. Each clear-cut was characterized by a regeneration regime (artificial or natural) and a succession age (2–6 years old). Sampling took place from 15 June to 23 August 2022, with one trap per clear-cut was hung at ~1.6 m, with a minimum distance of 50 m from the clear-cut edge. A sliding setup with 20 traps allowed continuous sampling across multiple clear-cuts, with each clear-cut sampled four times, yielding 200 samples. In the reference study, moths were sampled within each pair of forest and adjacent meadow (7 July–19 August 2023). The traps were placed ~100 m apart and ~50 m from habitat boundaries, sampled weekly for six weeks (36 events).

In study **III**, we studied how did three habitat types—selected along a gradient from natural to heavily human-altered environments (from forest, river to olive groves)— differ in terms of moth assemblages. Sampling was conducted in eight villages in the Zat sub-basin, over 13 days between 22 September and 15 November 2022. A total of 24 traps were deployed, with one trap per habitat type (river and olive) and two traps in forests. Traps within each village were spaced at least 100 m apart and relocated by a minimum of 30 m between sampling rounds to reduce microsite effects. Depending on temperature, traps were checked and replenished every 3–7 days. Three villages were replaced during the study due to technical issues or local conflicts, while five villages were sampled throughout the full period.

In study **IV**, we examined the effect of land use change on moth assemblages in Taddart village in the Ghdat sub-basin. Moths were sampled in 20 plots, differing from each other in the proportion of different land use types (natural vegetation, orchards, herbaceous field crops, and built-up areas). A single trap was placed at the center of each plot, deployed overnight, and collected the following morning. Sampling occurred on eight dates in 2021, covering early summer (13, 20, 27 June and 4 July) and autumn (18, 26 September and 2, 9 October) to assess seasonal variation in moth communities. Traps remained fixed in their positions throughout the study.

Identification of moths was primarily based on morphological characters, with DNA barcoding applied when necessary (Papers **III** and **IV**). Across all studies, nearly all individuals were identified to species level, with only a few remaining at the genus level (Paper **III** and **IV**). The faunistic data and species identification details for studies **III** and **IV** have been published in a separate paper (Fetnassi et al., 2025) that is not included in this thesis.

Fig. 4: A bait trap in an Estonian forest clear-cut with a portable weather station next to it. (Source: Study **I**).

2.3. Data analysis

We investigated the influence of weather parameters on bait trap catches (**I**) and the responses of moth assemblages to habitat characteristics **(II, III, IV)** based on bait trap catches. Prior to analyses for studies **II** and **III**, we estimated species richness and diversity on the study plots using rarefaction (interpolation) and extrapolation to correct for differences in sample size and sampling completeness. Diversity was quantified with Hill numbers, where q = 0 represents species richness, q = 1 corresponds to the exponential of Shannon's entropy index, and q = 2 corresponds to the inverse of Simpson's concentration index. Initially, these metrics were calculated directly from the observed data to obtain actual diversity values for each site. Subsequently, diversity was standardized to a sampling coverage of 50% to enable fair comparisons across sites despite varying sampling efforts (Chao et al., 2014, 2021; Hsieh et al., 2016). These standardized diversity estimates were then used as dependent variables in generalized linear mixed models for further analysis.

General linear mixed models (GLMMs) were applied to test the effects of weather parameters **(I)**, habitat types (forest, river and olive) **(III)**, and land-use type proportions (natural, herbaceous field crops, orchards and residential areas)

(IV) on moth abundance, species richness, and diversity. In addition, Bayesian regression models were used to examine how clear-cut characteristics (regeneration regimes; artificial and natural as well as age: from 2 to 6 years old) influence species richness and diversity. For these analyses, both simple models (single predictors) and multiple regression models (all predictors simultaneously) were fitted **(II)**. To refine the models, initial full models were simplified through backward elimination, retaining only statistically significant predictors in the final versions. Model performance and selection in studies **I** and **IV** were further evaluated using the Akaike Information Criterion (AIC).

Differences in species composition were assessed using permutational multivariate analysis of variance (PERMANOVA) in studies **II** and **III**. Non-metric multidimensional scaling (NMDS) was applied to visualize community dissimilarities: between clear-cut characteristics and habitats (clear-cuts, forests, and meadows) using Chord distance **(II)**, and between habitat types and villages using Jaccard distance **(III)**. In study **IV**, heatmaps based on Bray–Curtis distance were used to display compositional differences between study sites and seasons. To compare moth assemblages on clear-cuts with forest fauna along the successional gradient, we developed an index of similarity with forest assemblages derived from indicator species analysis (see paper **II** for calculation details). The latter analysis was also applied to identify species associated with 1) each clear-cut regeneration regime, forests, and meadows (**II**), and 2) each habitat type and village (**III**).

3. RESULTS AND DISCUSSION

3.1. Effect of weather parameters on sugar bait catches (I)

In this study, 864 macroheteroceran moths representing 59 species (primarily Noctuidae and Erebidae) were trapped over 32 nights (160 trap nights) using automatic sugar bait traps, with weather data recorded by portable stations placed near each trap. After controlling for seasonal changes in moth activity and phenology, temperature emerged as the strongest determinant of both abundance and diversity, consistent with previous studies (Yela & Holyoak, 1997; Jonason et al., 2014).

Warmer nights supported significantly higher moth catches, with abundance nearly doubling on the warmest nights compared to average nights, while catches were close to zero on the coldest nights. This pattern reflects the poikilothermic nature of insects, which rely heavily on ambient temperatures to regulate metabolic processes, flight activity, and foraging behavior. Air humidity consistently reduced both abundance and diversity, suggesting that high moisture levels may either directly inhibit moth flight or reduce their responsiveness to bait. Unlike light traps, where fog formation has been proposed as a limiting factor (Jonason et al., 2014), the negative effect of humidity in bait traps is more likely linked to behavioral mechanisms: on humid nights, moths may more readily locate natural sugar sources, reducing their need to visit artificial baits, and the physiological drive to seek water from nectar may be lower (Contreras et al., 2013).

High air pressure did not affect overall abundance but negatively influenced diversity, and this effect persisted even after controlling for temperature and humidity. This suggests a possible direct influence of air pressure on moth behavior. Interestingly, diversity increased when air pressure rose overnight, a pattern opposite to expectations based on the frequently suggested positive association of insect activity with falling pressure preceding rainfall (Pellegrino et al., 2013; Austin et al., 2014 ; Zagvazdina et al., 2015). Wind speed and rainfall did not have significant effects on either abundance or diversity, likely because the study period was characterized by generally weak winds and low rainfall, preventing extreme conditions that might disrupt flight or trap efficiency (Yela & Holyoak 1997; Jonason et al., 2024; Komatsu et al., 2020).

The results further showed that nightly averages of weather parameters were sufficient to explain patterns in moth catches, as alternative representations of these parameters (maxima and minima of the full night; averages, maxima and minima for the first half of the night) did not improve model performance, highlighting that moth responses are closely aligned with prevailing environmental conditions during the night.

3.2. Effect of habitat parameters on nocturnal moth diversity (II, III and IV)

We investigated the effect of various habitat types and their characteristics on nocturnal moth assemblages in Estonia and Morocco. Study **II** was conducted in clear-cuts of mixed hemiboreal forests of northern Europe. By contrasting two distinct reforestation trajectories in production forests (artificial and natural regeneration), we examined species richness and diversity on clear-cuts aged 2–6 years post-logging. The study recorded 9,362 macroheteroceran moths representing 196 species across 50 clear-cut sites in Estonia, with most species belonging to Noctuidae with additional representation of Erebidae, Drepanidae, Geometridae, and Sphingidae.

Time since clear-cutting had no effect on overall richness. However, species richness and diversity were somewhat lower in naturally regenerating clear-cuts compared to the artificially regenerating ones. This is likely because management maintained open habitats and prevented overgrowth by pioneer plants such as *P. tremula* and *R. idaeus*, which quickly dominated the naturally regenerating clear-cuts. Without thinning, reduced light availability must lead to a decrease in the diversity of undergrowth plant species (Depauw et al., 2020; Márialigeti et al., 2016), consequently supporting less diverse moth assemblages (Root et al., 2017; Uhl et al., 2020). Compared to other sites, clear-cuts where *A. incana* was harvested showed markedly reduced species richness and diversity, whereas species richness was slightly higher on those where *P. abies* had been growing. In addition, moth species richness generally declined as clear-cut size increased. This observed reduction in species richness with expanding clear-cut area is consistent with the widely documented positive association between habitat heterogeneity and biodiversity, a relationship evident even at fine spatial scales (e.g. Foerster et al., 2020; Serafini et al., 2019; but see Tamme et al., 2010).

Studies **III** and **IV** were conducted in the central High Atlas Mountains of Morocco. A total of 4,553 macroheteroceran moths representing 123 species were recorded, with the assemblages being dominated by Noctuidae and Erebidae. In the multi-village survey **(III)**, species richness and abundance were the highest in olive groves, while river and forest habitats showed no significant differences. Richness and abundance declined over the season, and forests hosted a disproportionately high number of rare species (Fig.5). In the single-village study at Taddart **(IV)**, land use strongly influenced moth communities: herbaceous field crops and orchards supported higher abundance, richness, and diversity. The share of natural vegetation exhibited non-significant negative association with moth assemblages, while the proportion of fallow land surrounding the traps showed no consistent effect (Table 2). Irrigated field crops may provide favorable microclimates and continuous food resources during the dry season (González-Estébanez et al., 2011; Pérez-Fuertes et al., 2015). In Mediterranean climates regions, such conditions can sustain diverse and abundant moth communities (e.g. Calabrese et al., 2012; Chafaa et al., 2019), which are frequently dominated by polyphagous generalist species, including major agricultural pests (e.g. Muddashar et al., 2017; Hinojosa-Dávalos et al., 2025) **(III** and **IV)**.

Although agricultural habitats such as olive groves can support high species diversity, the presence of natural vegetation may nevertheless remain essential for maintaining the full spectrum of species (Zucco et al., 2024). However, in Morocco, such natural areas are increasingly threatened by human activities, including firewood collection, overgrazing, and land clearing (El Alami et al., 2013; El Alami, 2022). In our studies in Atlas mountains, river habitats consistently showed lower species richness and abundance, likely due to fragmentation and degradation from rubble extraction, flooding, and vegetation loss, which reduce host plant availability for herbivorous insects (Assahira et al., 2017; Zkhiri et al., 2017; Mostakim et al., 2022a) **(III)**.

In Taddart study sites **(IV)**, natural areas dominated by Aleppo pine (*P. halepensis*) supported lower moth diversity, likely due to the limited use of this tree as a food resource by moths and the relatively small proportion of the natural habitat (~21% of the landscape). Residential areas exhibited weak, non-significant positive associations with moth abundance and diversity, likely due to the still low population density and minimal disturbance in the study villages, in contrast to more heavily urbanized environments **(IV)**.

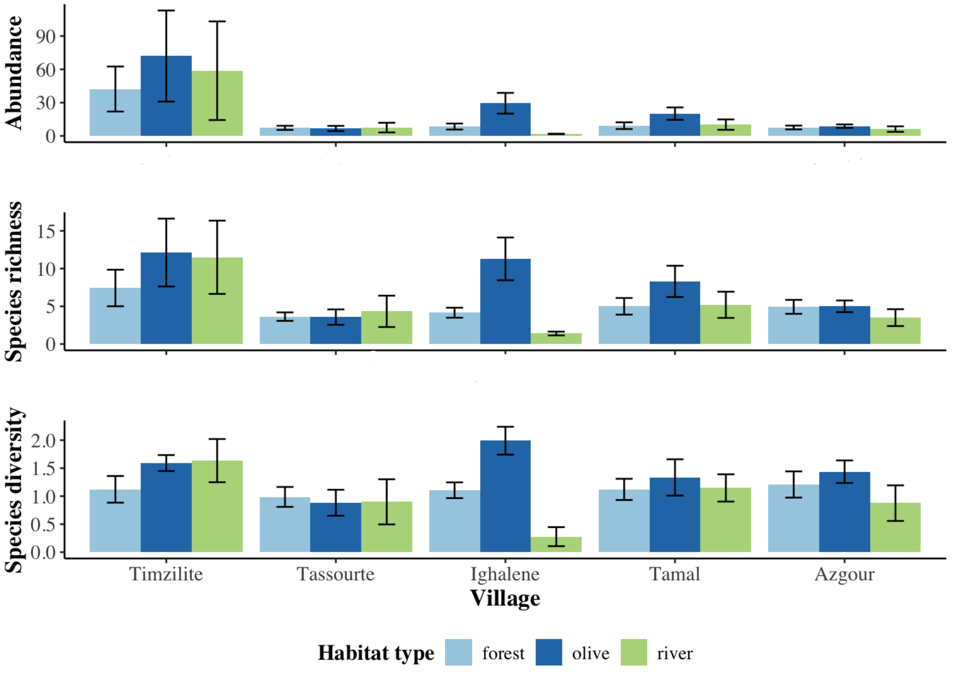

Fig. 5: Abundance, observed species richness and diversity (Shannon index) for each habitat type within each village. Villages are arranged based on altitude from the lowest to the highest (left to right). Error bars represent the standard errors of each of the three variables. (Source: Study **III**).

Table 2: Effect of land use types and their proportions on moth abundance, species richness and diversity. Only the best-fitting models, as indicated by lower cAIC values, are presented (See paper **IV** for more details).

	Abundance		**Species richness**		**Species diversity**	
Variables	Estimates	**P value**	Estimate s	**P value**	Estimates	**P value**
Field crops	0.02	**<0.001**	0.015	**0.002**	0.014	**0.04**
Orchards	0.013	**0.02**	0.013	**0.007**	0.021	**0.008**
Natural vegetation	–	–	–	–	–	–
Build-up	0.023	0.16	0.014	0.28	–0.005	0.66
Fallow	–	–	–	–	–	–
Season	–0.29	0.39	–0.41	0.11	–0.65	0.08
Catocala abundance	–	–	–	–	–	–

3.3. Community composition differences across landscape types (II, III and IV)

In the study on Estonian clearcuts **(II),** the analysis revealed that moth assemblage composition was not significantly structured by habitat characteristics so that there were only minor differences among groups as confirmed by PERMANOVA analysis and visualized by NMDS ordination. Moth communities in artificially regenerated clear-cuts were slightly more similar to meadows than naturally regenerating sites (Fig. 6). Forest index values indicated that clear-cut assemblages occupied an intermediate position between forest and meadow references, with the proportion of forest specialists generally increasing with clear-cut age, though even 6-year-old sites remained distinct from mature forests (Fig. 7). Indicator species analysis identified 38 grassland-associated moth species (12 of them nearly absent from clear-cuts) versus 8 forest-associated species; artificial regeneration had 14 indicator moths, while naturally regenerating clear-cuts had none. Some grassland indicator species were more frequent in artificially regenerated sites, suggesting that maintaining open structures benefits certain habitat specialists. Additionally, early successional host plants, such as *Rubus idaeus*, supported certain forest species across all clear-cut ages.

Despite the high overall diversity of moths in clear-cuts, several widespread noctuid species typical of semi-natural grasslands were virtually absent. Although the clear-cut and reference studies were conducted in different years, the observed patterns are unlikely to be due to interannual variation. These grassland-associated species were consistently abundant across Estonia in 2022 and 2023 but were nearly absent in clear-cuts also in our earlier study **(I)**. This indicates that clear-cuts do not provide suitable habitat for many dominant grassland noctuids. In contrast, according to previous research (Viljur & Teder, 2016; Viljur et al., 2020; Tammaru et al., 2023), grassland butterflies appear to thrive in clear-cut areas, implying that factors such as microclimatic conditions, rather than host-plant availability may primarily constrain the occurrence of nocturnal moths in these habitats. For example, the absence—or patchiness—of a compact turf formed by densely growing graminoid roots in clear-cuts may remove a key microhabitat for noctuid larvae, which typically shelter on or in the soil during the daytime.

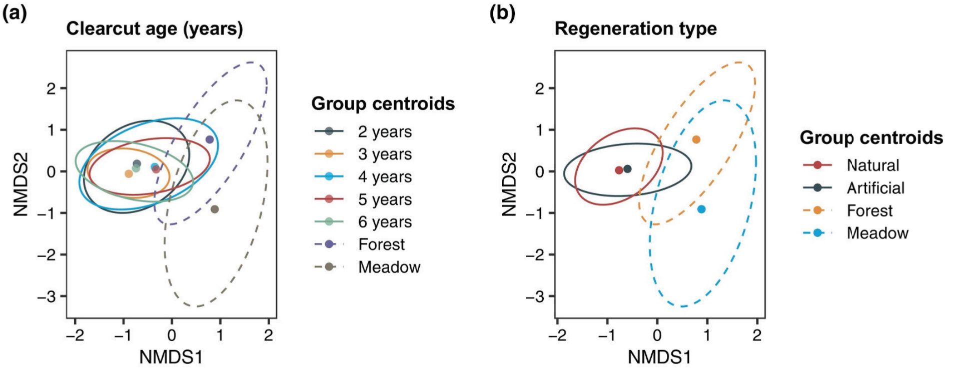

Fig. 6: Non-metric multidimensional scaling (NMDS) ordination of moth species composition (based on Chord distances) in Estonian clear-cuts of different regeneration regimes and ages, compared with forests and meadows. (Source: Study **II**).

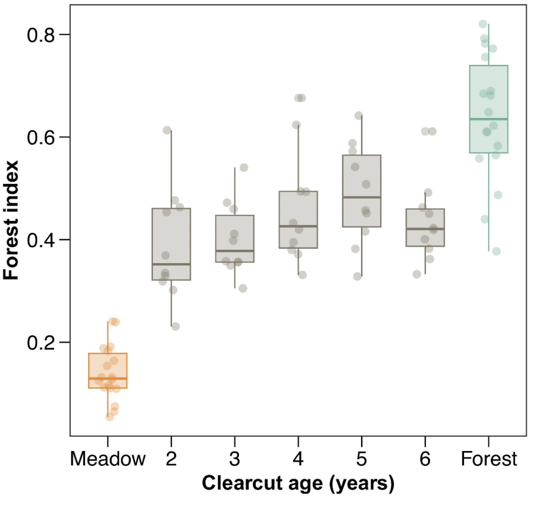

Fig. 7: Forest index (FI) values for moth assemblages in Estonian clear-cuts of different ages. The FI quantifies the degree to which a site exhibits forest characteristics based on its moth community. For comparison, values were also calculated for forest and meadow reference sites. (Source: Study **II**).

In study **III**, the analysis of species composition differences across an agricultural landscape in Morocco revealed notable variation in moth species composition among villages, as confirmed by PERMANOVA (Table 3–4) and visualized by NMDS. Species composition also differed systematically across habitat types, with consistent patterns across all villages in NMDS ordinations. Overall, variation among villages was slightly greater than that among habitats within villages, indicating that moth diversity is not evenly distributed across the landscape (Fig. 8). This spatial heterogeneity suggests that different areas contribute uniquely to regional biodiversity, highlighting the need for site-specific conservation and the protection of a network of habitats rather than single habitat types.

Table 3: Results of permutational analysis of variance (PERMANOVA) testing differences in moth community composition among villages, with villages treated as nested within habitat types. The analysis was based on Jaccard dissimilarities. (Source: Study **III**).

	Df	**SS**	**R^2**	**F**	**P**
Habitat type	2	1.186	0.028	1.462	
Phenology	1	1.923	0.037	4.768	
Village	7	3.494	0.067	1.231	**<0.001**
Study site	13	7.126	0.136	1.353	
Residual	95	38.501	0.738		
Total	118	52.238	1.0		

Table 4: Results of permutational analysis of variance (PERMANOVA) testing differences in moth community composition among habitat types, with habitats treated as nested within villages. The analysis was based on Jaccard dissimilarities (Source: Study **III**).

	Df	**SS**	**R^2**	**F**	**P**
Village	7	5.124	0.099	1.806	
Phenology	1	1.825	0.035	4.504	
Habitat type	2	1.054	0.020	1.301	**0.021**
Study site	13	5.734	0.110	1.090	
Residual	95	38.501	0.738		
Total	118	52.238	1.0		

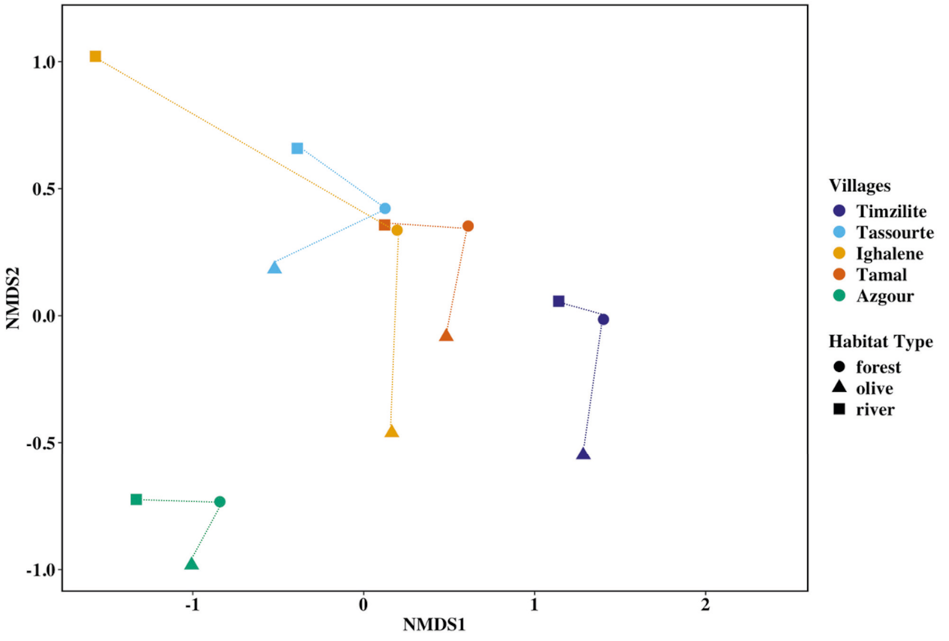

Fig. 8: Non-metric multidimensional scaling (NMDS) plots based on Jaccard distances, illustrating differences in moth species composition among habitat types and villages. Each point represents the moth community at a site (habitat type within a village). (Source: Study **III**).

In study **IV**, community composition analyses revealed strong spatial and temporal turnover in moth assemblages. Bray–Curtis dissimilarity values were moderate to high for most site pairs and species composition varied significantly both among sites within the same season, and between seasons across sites, indicating that both habitat heterogeneity and seasonality strongly shape moth community structure (Fig. 9). Our findings demonstrated that despite the small spatial scale, high dissimilarity in moth species composition was observed among sites and seasons, reflecting substantial habitat heterogeneity. These patterns align with previous studies showing that habitat diversity positively influences macro-moth assemblages (Botham et al., 2015; Reiss-Woolever et al., 2023), even across short distances. The findings emphasize the importance of conserving landscape heterogeneity and maintaining a mosaic of habitat types to sustain insect diversity and ecological functions.

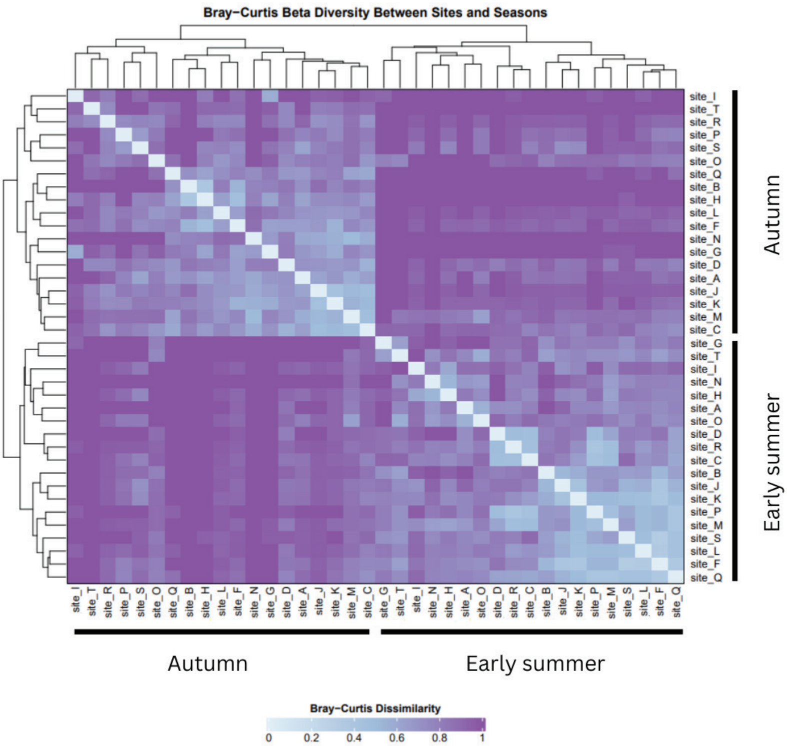

Fig. 9: Bray–Curtis dissimilarity among macro-moth communities across sites and seasons. Darker shades indicate greater dissimilarity in species composition between two sites (Source: Study **IV**).

4. CONCLUSIONS

In this thesis, I investigated whether moths could benefit from some anthropogenic habitats as alternatives to their declining natural environment. The research was conducted in two geographically distinct regions. In Estonia, assemblages were compared across clear-cuts of varying ages and regeneration regimes, alongside adjacent forests and meadows. In Morocco, the study area was situated in the semi-arid High Atlas Mountains, a recognized biodiversity hotspot, and encompassed a gradient of habitat types, including natural, semi-natural, agricultural, and built-up areas. All investigations employed sugar-bait traps, a relatively underutilized technique in ecological studies, the efficiency of which was also systematically evaluated within this work. I conclude that:

1. Clear-cuts in semiboreal forests support a considerable share of the regional moth community and should be recognized as a distinct habitat type beyond the forest–grassland dichotomy. Although artificial regeneration practice slightly increased species richness and favored some grassland species, the overall effect of clear-cut management on moth assemblages was limited. Clear-cuts failed to host many common grassland moths, indicating that this novel habitat still cannot fully substitute for semi-natural grasslands, maintaining of which remains thus a conservation priority. Conversely, most forest-associated moths occurred on clear-cuts, but the absence of some widespread species highlights the value of heterogeneous forest landscapes encompassing all successional stages.

2. Traditionally managed agricultural landscapes, particularly irrigated olive groves and field crops, can sustain higher moth abundance and diversity than natural areas in semi-arid conditions. These findings challenge the common view that agriculture is invariably detrimental to insect populations and highlight the conservation value of well-managed agroecosystems. Significant habitat heterogeneity contributed to variation in species composition, underscoring the need to preserve a heterogeneous mosaic of agricultural and natural habitats to maintain overall community diversity. The results emphasize that conserving diverse habitat types, alongside long-term monitoring, is essential for sustaining moth biodiversity and ecological functions in the face of land-use change and climate variability.

3. Sugar-bait trapping proved to be an efficient and practical method for investigating nocturnal moth assemblages at small spatial scales, even under semi-arid conditions. While it avoids some of the biases inherent to light trapping, its efficiency is influenced by weather, requires frequent maintenance, and shows strong taxonomic bias toward groups with adult feeding. As such, abundance estimates should be interpreted with caution, whereas community composition measures are more reliable.

SUMMARY

Natural ecosystems are under increasing anthropogenic pressure from activities such as timber extraction, agriculture, and urban expansion. However, certain human-made habitats may serve as refuges for various taxa in the face of ecosystem decline, or as temporary substitute habitats during dry periods in semi-arid landscapes. In this thesis, I explored how different human-induced habitat changes influence insects, focusing specifically on moths as a model group and using sugar-bait traps to study their assemblages.

For instance, clear-cuts, the main open habitats in production forests, may provide temporary refuge for some species of declining semi-natural grasslands. As one of its aims, the present thesis project examined nocturnal macro-moth assemblages in clear-cuts with different regeneration regimes and age as well as forest-meadow reference sites in northern Europe using sugar-bait traps over two summers. Clear-cuts were found to support high moth diversity, though several grasslands and some forest species were largely absent. Assemblage similarity to forests increased with clear-cut age, but overall, clear-cut characteristics had limited influence. Artificially regenerated clear-cuts supported slightly higher species richness and diversity than naturally regenerated ones. Clear-cuts can contribute to maintaining insect biodiversity and should be recognized as a distinct habitat type, but they cannot fully replace semi-natural grasslands, emphasizing the need for their conservation.

Research on the human impact on biodiversity remains uneven both geographically and taxonomically. While it has been studied elsewhere, data from North Africa, Morocco in particular, are scarce. In my thesis, I present results from two studies in the semi-arid High Atlas Mountains, using nocturnal moths to assess impacts of land use on biodiversity.

The first study examined the effects of land-use change—including agricultural and residential areas—on moth assemblages, comparing them to natural habitats such as forests and riparian vegetation in the vicinity of a village with intensive agricultural activity. Automatic sugar bait traps were deployed across the village, encompassing sites with different proportions of land use types. Our results showed that moth abundance, species richness, and diversity were positively associated with the share of agricultural crops in the surroundings. Natural habitat cover exhibited a negative relationship with the three-community metrics, whereas the share of residential areas showed a positive, though non-significant, association.

In a follow-up study, moth communities were compared across three habitat types—forest, riverbanks, and olive groves—along a gradient of natural to heavily altered environments in eight villages, spanning an altitudinal range of over 500 meters. The differences in moth assemblages among the studied habitats were statistically significant, with magnitudes comparable to those observed among the study sites. Moth abundance and species richness varied across the villages, with the lowest altitude village showing notably higher values for both

metrics. Olive groves exhibited the highest moth abundance and species richness, though were dominated by common species, while forests supported a higher proportion of rare species, and riverbanks had the lowest diversity. Our findings indicate that traditional irrigation methods used in agricultural habitats facilitate sustaining surprisingly high levels of moth diversity within these largely arid landscapes. Although traditional agriculture can support rich insect communities in semi-arid regions, preserving natural vegetation remains essential, as forests—despite hosting fewer species—still play an important role in boosting overall moth diversity. Additionally, our study fills a significant knowledge gap regarding moth diversity in North Africa and offers a critical baseline for future conservation initiatives.

As a methodological note, light trapping has long been the predominant method for quantitative research on moth communities, but it is inherently biased by habitat-specific variation in light conditions. Bait trapping avoids this shortcoming, though its efficiency can still be affected by weather. In situ recording of weather parameters can therefore provide valuable data for assessing the weather sensitivity of insect trapping, which is essential for accurately interpreting trap-based abundance data in both ecological and applied contexts. Our results showed that associations between Shannon diversity and weather variables were clearer than those for total abundance, likely because total abundance is more susceptible to high local fluctuations caused by exceptionally abundant species. Improving our quantitative understanding of these effects can enhance the reliability of bait trapping and encourage its wider use in insect monitoring projects.

SUMMARY IN ESTONIAN

Liblikakooslusi kujundavad tegurid Eesti ja Maroko inimmõjulistes maastikes

Inimtegevus mõjutab järjest enam looduslikke ökosüsteeme, seda läbi üha intensiivistuva põllumajanduse, metsamajanduse ja linnastumise. Antropogeensed mõjurid põhjustavad looduslike koosluste muutumist ja pahatihti paraku ka nende märkimisväärset vaesumist. Ometi võivad teatud inimtekkelised elupaigad toimida paljudele liikidele pelgupaikadena (pool)looduslike ökosüsteemide taandumise tingimustes või ka näiteks ajutiste asenduselupaikadena ariidsetes keskkondades põuaperioodide ajal. Mitmekülgne, eelarvamustest vaba inimmõjude analüüs on eelduseks teaduspõhistele säästliku arengu visioonidele.

Käesolevas doktoritöös uuriti inimtekkeliste elupaikade olulisust ööliblikatele kahes keskkonnatingimuste poolest erinevas piirkonnas – Eestis ja Marokos. Liblikad on tänuväärne mudeltakson mitmesugustes ökoloogilistes uurimustes tänu nende suurele arvukusele, liigirikkusele, suhteliselt lihtsale vaadeldavusele ja määratavusele ning ka seetõttu, et üksikute liikide arvukus ja liblikakoosluste koosseis reageerivad keskkonnamuutustele väga kiiresti. Töös uuriti liblikakooslusi erinevatesse elupaikadesse asetatud söödapüüniste abil ehk meetodil, mis tugineb paljude liblikaliikide valmikute toitumisel suhkrurikastest vedelikest – selliseid liblikaid saab püünisesse meelitada sobivalt lõhnavate söötade abil. Kuna söödapüüki on ökoloogilistes uurimistöödes seni teenimatult vähe kasutatud, sisaldub töös ka söödapüügi efektiivsust uuriv metodoloogiline artikkel.

Eestis uuriti inimtekkeliste koosluste näitena raiesmikke, mis on peamised avatud elupaigad Põhja-Euroopa majandatavates metsades. Piirkondlikus looduskaitselises kontekstis on oluline, et raiesmikud võivad pakkuda sobivaid elupaiku taanduvate poollooduslike niitudega seotud liikidele. Töö üheks eesmärgiks oligi uurida ööliblikate kooslusi erineva uuenemisrežiimi ja vanusega raiesmikel ning võrdlevalt ka metsades ja niitudel, seda rõhuga just niitudega seotud liblikaliikidel. Uurimistulemused näitasid, et raiesmikel on küll üldiselt suur liblikate mitmekesisus, kuid mitmed tüüpilised niiduliigid ja osa metsaliike neilt peaaegu puuduvad. Selles osas erinevad ööliblikad päevaliblikatest, kes pea kõik saavad Eesti raiesmikel väga hästi hakkama. Raiesmike ööliblikakoosluste sarnasus metsakooslustega suurenes ootuspäraselt raiesmike vanuse kasvades, kuid muude raiesmikke iseloomustavate parameetrite mõju oli vähene. Kunstlikult uuendatavatel raielankidel registreeriti liblikate veidi suurem liigirikkus ja mitmekesisus kui looduslikult uuenevatel lankidel. Raiesmike roll putukate mitmekesisuse säilitamisel on igal juhul oluline ning neid tuleks käsitleda eraldiseisva elupaigatüübina, mis küll sarnaneb paljuski poollooduslikele niitudele, kuid ei suuda neid täielikult asendada. Viimaste alahoidmine on seega endiselt oluline.

Inimtegevuse mõju elurikkusele on ebaühtlaselt uuritud nii geograafilises kui ka taksonoomilises plaanis. Kui mitmel pool maailmas on sellele põhjalikku tähelepanu pööratud, siis Põhja-Aafrika, sh Maroko kohta on andmeid siiani vähe. Käesolev doktoritöö hõlmab kahte uuringut poolkõrbelise kliimaga Atlase mägedest, kus ööliblikakooslusi kasutati maakasutuse mõju elurikkusele hindamiseks. Ühe uurimistöö eesmärk oli analüüsida põllumajanduse ja asulate läheduse mõju liblikatele traditsioonilisel agraarmaastikul, seda võrdluses poollooduslike kooslustega (nõlvadel kasvav mets ja jõeäärne taimekooslus). Söödapüünised paigutati ühe küla piires paljudele uurimisaladele, mis erinesid maakasutuse poolest. Tulemused näitasid, et liblikate arvukus, liigirikkus ja mitmekesisus olid positiivselt seotud põllumaa osakaaluga püünise ümbruses. Seevastu avaldas looduslike elupaikade osakaal koosluse parameetritele (arvukus, liigirikkus, mitmekesisus) negatiivset mõju, samas kui inimasustuse mõju oli nõrk ja pigem positiivne.

Järgnevas, suuremat geograafilist skaalat hõlmavas töös võrreldi liblikakooslusi kolmes diskreetses Maroko keskmäestiku elupaigatüübis – metsades, jõeäärsetel aladel ja oliivisaludes –, mis moodustasid gradiendi looduslikest tugevalt inimmõjuliste elupaikadeni. Erinevused eri elupaikade liblikakoosluste vahel osutusid statistiliselt oluliseks ning nende suurusjärk oli võrreldav uurimisalade (külade) vaheliste erinevustega. Ka liblikate arvukus ja liigirikkus erinesid külade lõikes. Kõige madalamal paiknevas külas olid mõlemad näitajad märkimisväärselt kõrgemad kui kõrgemal mägedes asetsevates külades, kuid viimaste omavahelises võrdluses selget seost kõrgusega merepinnast ei ilmnenud. Suurim liblikate arvukus ja liigirikkus leiti olevat oliivisaludes, kuid seal domineerisid tavalised ja laialt levinud liigid, samas kui metsades oli rohkem vähearvukaid liike; jõeäärsetel aladel täheldati madalaimat mitmekesisust. Marokos läbi viidud uurimuste tulemused viitavad sellele, et poolkõrbelistes oludes toetavad traditsioonilised põllumaa niisutamise meetodid liblikate kõrget mitmekesisust. Kuigi traditsiooniline põllumajandus võib sellistes piirkondades avaldada positiivset mõju putukate liigirikkusele, on loodusliku taimestiku säilitamine siiski vältimatu, kuna metsad – vaatamata väiksemale liigirikkusele – täidavad olulist rolli mitmekesisuse alalhoidmisel suuremal skaalal. Atlase mäestikus läbi viidud ökoloogiliste uurimuste lisaväärtuseks on teadmiste täienemine seni suhteliselt vähe uuritud Põhja-Aafrika liblikate mitmekesisusest, mis loob olulise tõukepunkti edasiseks looduskaitsebioloogiliseks tööks piirkonnas.

Töö metodoloogiline väärtus seisneb söödapüügi kasutusvõimaluste hindamises liblikakoosluste uurimise meetodina. Traditsiooniliselt on valguspüük olnud ööliblikate koosluste kvantitatiivse uurimise peamine meetod, kuid selle tulemused on paratamatult kallutatud mh seetõttu, et võrreldavates elupaikades on sageli erinevad valgusolud, mis mõjutavad valguspüügi efektiivsust ja võivad seeläbi saada süstemaatilise vea allikaks. Söödapüük on sellest probleemist vaba, ehkki ka selle meetodi tõhusus sõltub ilmastikutingimustest, mida on seega põhjust arvestada söödapüügi andmete kvantitatiivsel analüüsil. Käesoleva doktoritöö osana uuritigi söödapüügi tulemuste sõltuvust ilmast. Selgus, et söödapüügi efektiivsust mõjutab eelkõige temperatuur, kuid ka õhurõhu muutustel on oma osa. Ilmnes ka, et seosed mitmekesisuse ja ilmamuutujate vahel olid selgemad kui liblikate üldarvukuse puhul. Seda tõenäoliselt seetõttu, et viimast näitajat mõjutavad rohkem lokaalsed kõikumised, mida põhjustavad eriti arvukad liigid. Kvantitatiivne arusaam ilma mõjudest aitab tõsta söödapüügi usaldusväärsust uurimismeetodina ning soodustada selle laiemat rakendamist putukate seireprojektides.

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***

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Fetnassi, N., Ghamizi, M. (2018). The impact of light pollution on fauna: In particular moths (suuline ettekanne). The International Interdisciplinary Workshop on Light Pollution, Marrakech, Maroko 22.–26. oktoober 2018.

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