Master's Thesis

Assessing Biodiversity Change of Butterfly Species *(Macro-lepidoptera)* in Four Bioregions in Finland

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Abstract: Loss of biodiversity as a result of changes in land use and climate is a major hazard to ecosystems worldwide, including Finland. Effective conservation requires monitoring and measuring changes in biodiversity over time, but this was difficult owing to poor and restricted data availability. While national-level evaluations like the Red List is helpful to comprehend broad patterns in biodiversity loss and change, they may be unable to fully capture changes of the whole species community (all species) and regional differences. The purpose of this research was to assess and quantify butterfly *(Macro-lepidoptera)* biodiversity changes in Finland at the regional levels. The research made use of butterfly-specific biodiversity data culled from the Laji.fi database. Biodiversity indicators were calculated using the available data, and the rate and significatively of changes in biodiversity were evaluated using statistical analysis tool such as "R". The primary objectives of this study were to compare biodiversity trends recorded in different regions and evaluated the temporal changes in butterfly biodiversity. For efficient conservation planning and resource allocation, knowledge of biodiversity patterns across space and time is essential. The results of this thesis may inform conservationists and policymakers on how butterfly species in Finland are adjusting to changing environmental conditions.

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TERMS AND ABBREVATIONS

TERMS

Biodiversity: Biodiversity is the diversity and adaptability of living forms, including ecosystems, genetic differences within species, and species themselves.

Biodiversity conservation: is the management and protection of biodiversity to guarantee its long-term viability and resistance to pressures including pollution, climate change, and habitat loss.

Macro-lepidoptera: An order of enormous moths and butterflies, usually identified by their size and scaled wings.

Temporal Change: Changes or variations that occur over time.

Laji.fi Database: A Finnish biodiversity information portal that collects and provides access to data on various species, including butterflies.

Red List: An extensive list that highlights species at danger of extinction by assessing the state of worldwide conservation for plant and animal species.

Biodiversity Indicators: Quantities or measures of species richness, abundance, and distribution that are used to evaluate biodiversity.

Species Richness: In an ecological community, landscape, or region, species richness is the total number of distinct species.

Statistical Analysis Tool ("R"): A free software environment and programming language used for statistical computing and graphics; extensively used for data analysis in biodiversity research.

Conservation Planning: is the method of carefully organizing activities and distributing funds to preserve ecosystem services and biodiversity.

Habitat loss: is the loss of natural habitats as a result of which species that rely on such habitats suffer or become extinct.

Climatic Change: Prolonged variations in Earth's temperature, precipitation, and other climatic patterns, frequently linked to human activity like the combustion of fossil fuels and deforestation.

Policymakers: Individuals or groups responsible for creating and implementing laws, regulations, and policies that affect public and environmental health.

Regional differences: Variations in environmental, ecological, or biodiversity characteristics between different geographical areas.

ABBREVATIONS

UCL = Upper confidence limit.

LCL= Lower confidence limit.

1. INTRODUCTION

Biodiversity, the intricate interconnectedness of life on Earth, is facing unparalleled challenges due to alterations in land use and climate, resulting in profound ramifications for ecosystems worldwide. The current rate of extinctions suggests a catastrophic loss of biodiversity (Kukkonen et al. 2022; Ceballos et al. 2020).

Finland is susceptible to these hazards as a result of its diverse landscapes and ecosystems. Comprehending and monitoring the patterns of biodiversity across time is crucial for effective conservation efforts, although these efforts are often impeded by insufficient data and fragmentation. Despite the fact that national-level assessments, such as the Red List, provide valuable insights into general biodiversity patterns, they may not adequately reflect the intricate variations that take place across different regions.

As we know, insects comprise almost 50% of all documented species on Earth and play a multitude of vital roles in terrestrial ecosystems worldwide (Pinkert et al, 2022). Butterflies have been the focus of researches into apparent changes in their geographic distribution (Pöyry et al, 2009).

Species of butterflies may respond to climate change by either adapting in their current location or by migrating to other locations, and these two responses can work together to support and strengthen each other (Hälfors et al, 2021).

However, the species of butterflies that live in grasslands face additional difficulties as a result of climate change (Tainio et al, 2016; Warren et al, 2001, Wallisdevries and Van Swaay 2006). Traditionally managed semi-natural grasslands are among the environments in Europe that contain the greatest number of butterfly species, and it is essential that these grasslands be preserved in order to ensure the preservation of biodiversity (Tainio et al, 2016; Pykälä 2000; Kivinen et al. 2008; Kleijn et al. 2011).

Butterflies are regularly observed in Finnish agricultural landscapes due to their usefulness as indicators in open environments (Kuussaari et al., 2007). Agricultural landscapes face dual challenges: increasing food production for a growing population, while also maintaining biodiversity and ecological services (Mäkeläinen et al., 2019; Foley et al., 2011). On the other hand, according to Seto et al. (2012), urbanization is a major contributor to global biodiversity degradation because the worldwide population is increasingly concentrated in cities (Kuussaari et al, 2020).

However, Hällfors et al. (2021) utilized range and phenology data to ascertain species that exhibit heightened susceptibility to climate change and those that could potentially thrive under changing environmental conditions. They discovered that species that have coordinated expansions of their geographic range and advancements in their phenological events are more likely to succeed in adapting to changing climatic conditions. Conversely, species that have inconsistent or out-of-sync reactions may encounter more difficulties in coping with these changes. Moreover, the research undertaken by Hällfors et al., (2021) highlighted the significance of taking into account both changes in geographic distribution and timing of biological events in the development of conservation planning and management techniques. Gaining insight into the impact of climate change on species ranges and life cycle timings facilitates more efficient decision-making processes focused on safeguarding susceptible species and ecosystems.

In their study, Hällfors et al. (2021) emphasized the importance of combining range and phenology data to obtain a thorough knowledge of the effects of climate change on boreal Lepidoptera ecosystems. Their discoveries offer useful understanding of the mechanisms that influence how species react to environmental changes and have significant implications for the conservation and management of biodiversity in boreal regions.

The research undertaken by Pöyry et al. (2009) examined the extent of changes in the migration patterns of Finnish butterflies and the factors that influence these changes.
In their study, Pöyry et al. (2009) found that Finnish butterflies experienced a significant average range shift of over 60 km between the years 1992-1996 and 2000-2004. This pace of change surpassed all previously documented average range shift rates in insects globally. The notable shift in range, which is attributable to recent climate warming, emphasizes the need of comprehending the mechanisms that are causing these changes.
The study found that there were various characteristics of species that showed significant correlations with the observed changes in their geographic range. Butterflies that are not at risk of extinction were discovered to have significantly extended their geographic ranges towards the north, while species that are in danger of extinction showed no

significant change in their distributions. Furthermore, mobile butterflies that inhabit the borders of forests and rely on woody plants as hosts for their larvae were shown to have a higher tendency to move their habitats towards the northern regions. These findings emphasize the significance of habitat availability and the ability to disperse in determining how species react to climate change.

In addition, the study utilized hierarchical partitioning analysis to determine the primary reasons responsible for the observed changes in geographic distribution. The important elements that influence range shifts among Finnish butterflies were identified as butterfly mobility, principal breeding environment, and larval host plant growth type. This approach yielded useful information regarding the relative significance of several species features in influencing butterfly distributions. In the future, looking at how these features are related to the species richness changes observed in the present study could provide valuable information on which type of species are responsible for these changes.

In their study, Pöyry et al. (2009) showed that species features are essential in determining how climate change affects the distribution of butterflies. The study of individual features linked with range shifts enhances our comprehension of the mechanisms that drive changes in biodiversity and offers valuable insights for conservation endeavors in the context of ongoing climate change.

Pinkert et al. (2022) conducted a study that delves into the distribution patterns of butterfly species diversity on a global scale. Their research focuses on examining the disparities in butterfly species numbers across regions. By utilizing “publicly available occurrence records” from “Global Biodiversity Information Facility, (GBIF)” (Pinkert et al., 2022), the authors assess how the number of butterfly species varies in locations. Such investigations contribute to understand the factors that impact butterfly diversity and identifying areas of importance for conservation efforts (Pinkert et al., 2022).

In a recent study by Shirey et al. (2021), an investigation was carried out to assess the comprehensiveness and potential biases in the occurrence data of North American butterflies. The researchers utilized butterfly records from natural history collections and community science observations to assess the distribution of data in terms of both location and taxonomy. Significant under-sampling has been observed in regions experiencing significant climate change effects, spanning multiple biomes. The study revealed that community science observations were effectively addressing gaps in sampling, with a tendency to priorities regions with higher human presence. In addition, it is worth noting that both data sets exhibited biases at the taxonomic level, which challenges the assumption that natural history collecting data are free from taxonomic bias. Overall, the findings suggest a complex connection between data completeness and biases, emphasizing the importance of considering these factors in ecological research (Shirey et al., 2021).

Taking inspiration from the work done by Pinkert et al., we intend to conduct a study in which we will investigate the variety of butterfly species across different areas and latitudes. The occurrence database that we used for our analysis is of a similar type to the one in the cited research. In order to gain a more in-depth understanding of the trends in butterfly diversity, the objective of this thesis is to investigate the ways in which the richness of butterfly species differs across different regions and latitudinal zones. In order to help conservation efforts and advance ecological studies, the purpose of this research is to discover patterns in the distribution of butterfly species and investigate the factors that influence the dynamics of these species.

However, understanding the dynamics of butterfly biodiversity has gained significance in recent years because to its implications for ecosystem health and conservation endeavors. Butterfly population monitoring in Finland, a country with a range of ecosystems from agricultural landscapes to mostly boreal forests, as well as tundra and open peatland in the north, offers excellent insights into wider ecological patterns. Although there has been research on overall patterns of butterfly biodiversity, it is necessary to investigate the variations of these patterns in different biogeographic regions within Finland.

Therefore, this study aims to address two primary research questions:

1. What is the temporal trend in butterfly biodiversity throughout the four biogeographic regions of Finland?
2. What are the differences and similarities in butterfly biodiversity trends observed in the four biogeographic regions of Finland?

The research objectives aim to clarify the temporal patterns of butterfly biodiversity and investigate the potential mechanisms behind the variances in these trends across various locations. This research endeavor seeks to enhance our understanding of biodiversity patterns and develop conservation strategies by analyzing butterfly populations in different biogeographic contexts. The goal is to provide targeted conservation measures that address the unique requirements of each location.

2. MATERIALS AND METHODS

2.1 MATERIALS

Butterfly data was collected using laji.fi. The Laji.fi platform, which serves as an extensive repository offering biodiversity data for Finland. The surveys comprised observations and species identifications by trained entomologists and citizen scientists. Species records were downloaded with species name, time of observation, and biogeographic location of the observations. Species were filtered to keep only native *macro-lepidoptera*. These efforts focused on recording butterfly species in specific study areas.

Following that, we identify and retrieve records specifically linked to butterflies in the four biogeographic regions of Finland: Oulun-Pohjanmaa (OP), Keski-Pohjanmaa (KP), Satakunta (St), and Uusimaa (U). The datasets contained pertinent information

2.2 METHODS

After acquiring the data, we arranged it in a methodical way that is appropriate for analysis, guaranteeing uniformity and precision. The correctness of following analyses is ensured by verifying the geographical borders and classifications of the biogeographic regions.

Subsequently, we analyzed butterfly biodiversity indices by using the retrieved data through the R statistical analysis programme (See Appendix 1), a free software environment and programming language used for statistical computing and graphics; extensively used for data analysis in biodiversity research. The purpose of statistical analysis is to examine changes in butterfly biodiversity within specific biogeographic regions. This entails conducting statistical tests to compare biodiversity indices over distinct time periods, that is 1993-1997 and 2018-2022.

The statistical analysis of the butterfly species richness was assessed using the framework of species accumulation curve technique (Ugland et al., 2003) (See Appendix 1). This statistical approach uses observed species occurrences to estimate the species count in an area or dataset. The accumulation curve was created by plotting the cumulative number of detected species vs the number of observations. This method has assessed the species inventory's comprehensiveness and allowed judgements regarding the area's species diversity.The analyses were performed in R using the iNEXT package (Hsieh et al., 2016)

(See Appendix 1; for more details).

The study built the curve, assessed its shape, and estimated species richness parameters. This approach revealed whether the sample attempt captured all butterfly species in the research region.

The species accumulation curve is useful for assessing biodiversity and understanding species inventories. This approach may quantify butterfly species richness in the research region, improving understanding of Finnish butterfly communities.

3. RESULTS

Gaining insight into the changes that occur of ecological communities throughout time is essential for evaluating the health and variations of ecosystems. This study examines the changes in butterfly biodiversity throughout the years of 1993-1997 and 2018-2022 (Table 1 and 2). Specifically, we analyze the number of observed species (S.obs) and the sampling completeness index (SC.x). These metrics offer vital information about the variety and effectiveness of sampling in different biological groups. Through the examination of patterns in recorded species numbers, the degree of representative sampling, and the variability of estimations in different areas, we can get a more profound comprehension of the changes that biological communities have undergone in recent decades. This comparative approach establishes the foundation for future investigations into wider ecological patterns and solutions for conservation.

Assemblage	n	S.obs	SC.x	Estimator	s.e.	LCL	UCL
Oulun-Pohjanmaa (OP)	8784	271	0.997	281.3	9.3	271.0	299.5
Keski-Pohjanmaa (KP)	18050	313	0.998	344.1	12.3	319.9	368.2
Satakunta (St)	24950	528	0.998	570.5	19.6	531.86	609
Uusimaa (U)	76003	695	0.999	718.6	10.8	697.9	739.2

Table 1: Results of the accumulation curves data analysis of Data for *macro-lepidoptera* species records from 1993-1997.

Table Legend:

Assemblage: Refers to the different biogeographical region's studies ordered from North to South of Finland's ecological community or group of organisms being studied.

n: Represents the total number of samples or observations collected for the given assemblage;

S.obs: Indicates the observed species richness, i.e., the total number of distinct species observed within the studied assemblage.

SC.x: Denotes the sampling completeness index, a measure of how well the observed species richness represents the true species richness of the assemblage.

Estimator: The statistical method used to estimate the true species richness based on the observed data.

s.e.: Stands for standard error, a measure of the variability or precision of the estimator.

LCL: Represents the lower confidence limit, the lower bound of the confidence interval for the estimated species richness; .

UCL: Represents the upper confidence limit, the upper bound of the confidence interval for the estimated species richness.

Assemblage	n	S.obs	SC.x	Estimator	s.e.	LCL	UCL
Oulun-Pohjanmaa (OP)	26194	429	0.9984	458.03	21.3	443.2	526.8

Keski-Pohjanmaa (KP)	4730	410	0.9873	453.9	13.1	428.1	479.6
Satakunta (St)	42283	643	0.9989	685.4	16.5	653	717.8
Uusimaa (U)	141077	769	0.9998	795.9	11.3	773.6	818.2

Table 2: Results of the accumulation curves data analysis of *macro-lepidoptera* species records from 2018-2022. Explanation of the indicators are in Table 1.

In the assessment of ecological assemblages between the eras 1993-1997 and 2018-2022, significant focus points are the number of observed species (S.obs) and the sampling completeness index (SC.x). These variables provide crucial information on the dynamics of changes in butterfly biodiversity across time.

As a basic statistic, the number of observed species (S.obs) indicates the diversity within each biological assemblage. Notable alterations are identified among certain groups. For example, there is a discernible rise from 313 to 410 species in the (KP) region, suggesting that the extent of observed biodiversity may expand. In the (OP) region, a similar trend is shown, with the number of species increasing from 271 to 429. The (St) and (U) assemblages show similar increases, with counts rising from 528 to 643 and from 695 to 769 species, respectively.

In addition to the species count, the sample completeness index (SC.x) offers useful data on how well each species assemblage was assessed. SC.x in the (KP) assemblage shows a decline from 0.998 to 0.9873, indicating a possible drop in the sampling's completeness. On the other hand, (OP) shows a rise in SC.x from 0.9973 to 0.9984, which suggests an improvement in sampling completeness. In the meanwhile, the (St) and (U) assemblages also continue to exhibit consistently high SC.x values. Observed differences were very small and values close to 1, highlighting consistent and excellent sampling level.

Estimators provide further depth to the research by providing information on key trends in each assemblage. The estimator is related to species richness. Typically, the estimator employed in the analysis is a function that computes the species richness in accordance with the rarefaction/extrapolation method adopted.

While estimators vary, standard errors (s.e.) remain almost stable across the two time periods, indicating a steady level of measurement accuracy except a slight difference in the OP region. This stability suggests that, despite changes in central tendency, the reliability of measurements stays almost stable.

Delving into the variability of estimators, lower confidence limit and upper confidence limit (LCL and UCL) give extra contextual information. A rise in species richness is shown by the broadening of the interval in the (KP) region from 319.93 to 368.2 in 1993-1997 to 428.1 to 479.6 in 2018-2022. In a similar vein, the (OP) region observes an extended range from 271 to 299.5 to 443.2 to 526.8, suggesting increased estimate variability.

To sum up, this comparison study shows how observed species and sample completeness have changed dynamically between 1993–1997 and 2018–2022, which is indicative of how ecological assemblages have changed over time. Additional elucidation on the nature of the estimator would improve the accuracy of interpretations of central tendency in each group. The foundation for tackling more general research topics is laid by these discoveries.

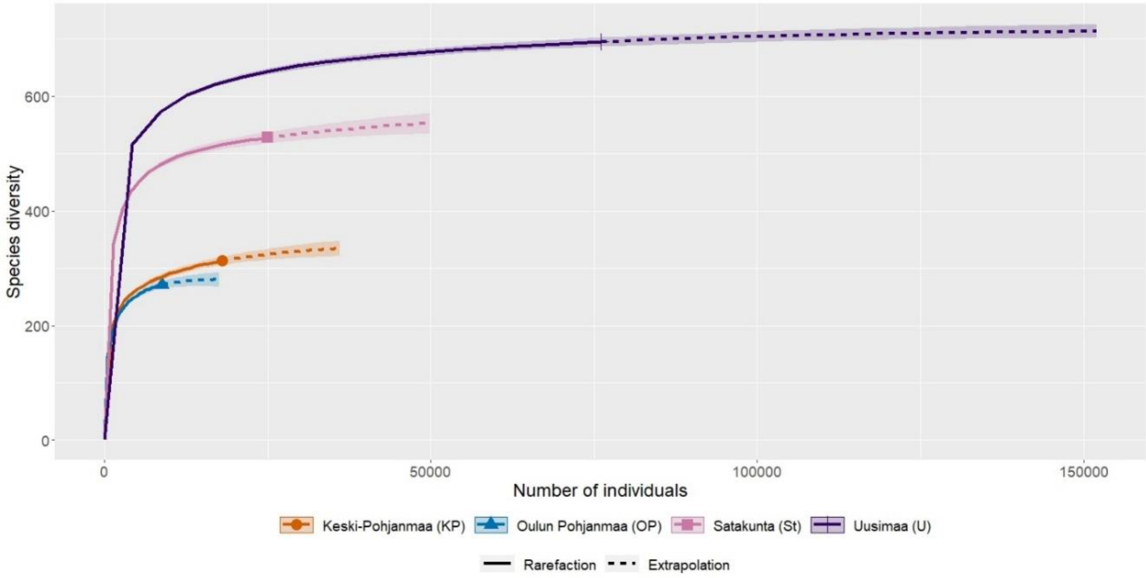

Figure 1: Species Accumulation Curve from 1993-1997

Figure 1 illustrates the species abundance observed in a sequence of butterfly surveys conducted across Finland. The x-axis represents the number of observations or number of individuals, while the y-axis represents the number of species that were discovered, mainly species diversity. Each color corresponds to a distinct area in Finland.

A species accumulation curve based on data from 1993 to 1997 is shown in Figure 1. This display illustrates the number of species that have been discovered in relation to the total number of observations. The information in this instance comes from research that was conducted in Finland between the years 1993 and 1997 and focused on four distinct regions: Keski-Pohjanmaa (KP), Oulun Pohjanmaa (OP), Satakunta (St), and Uusimaa (U).

One can observe that the curve begins with a sharp growth, but then the rate of increase begins to slow down as more and more species are discovered.

The extrapolations are shown by the dashed lines on the graph. For example, they illustrate what the curve may look like if a larger number of individuals were sampled. The fact that the extrapolations for the two northern areas (KP and OP) reach a point where they level out is indicative of the fact that these regions have achieved the maximum amount of species variety that they are capable of carrying. The fact that the extrapolations for the two southern areas (St and U) continue to climb is indicative of the fact that these regions still have a greater number of species to discover.

The curve depicts the link between species diversity and sampling effort. It may also help us identify areas that are likely to be beneficial for conservation.

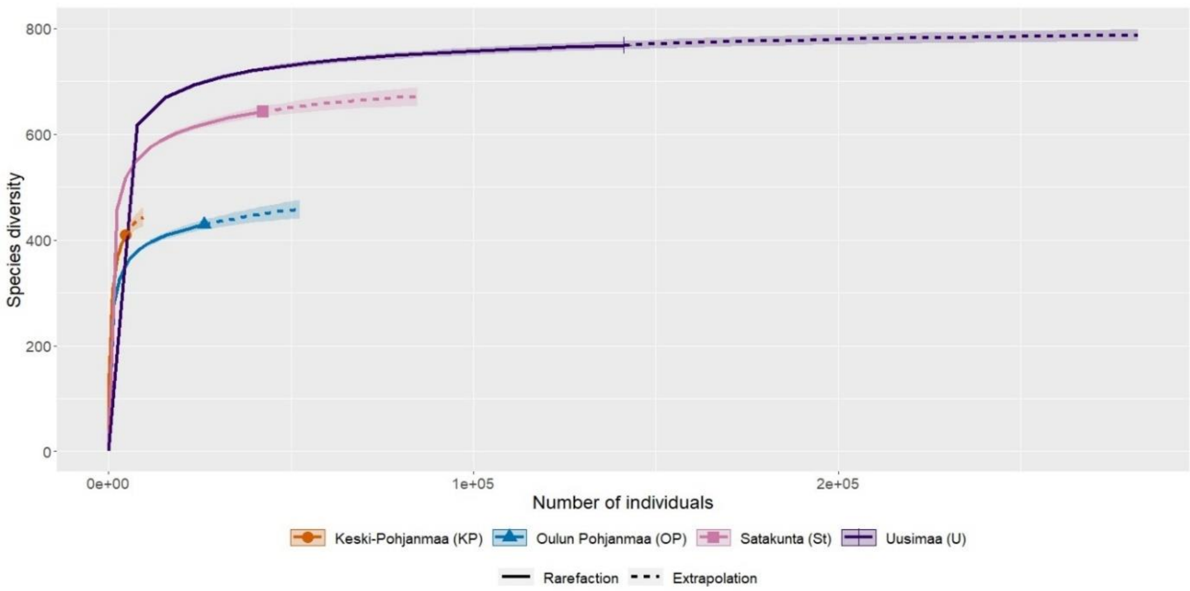

Figure 2: Species Accumulation Curve from 2018-2022

Figure 2 depicts the number of species discovered during a series of butterfly surveys in Finland from 2018 to 2022. The x-axis represents the number of observations or number of individuals, while the y-axis shows the number of species discovered or species diversity. The varied colors symbolize various areas of Finland.

As one can see on Figure 2, the number of species discovered rises as more individuals are sampled. This is because there are many common species that are simple to locate, and these species are the first to be discovered. However, as more samples are gathered, the number of new species discovered begins to fall. This is because news species are scarcer and harder to locate.

The dashed lines on the graph represent extrapolations, which means they anticipate how many species would exist if more individuals were sampled. Similarly to the figure1, the extrapolations for the two northern regions (Keski-Pohjanmaa and Oulun Pohjanmaa) almost level out, indicating that these areas have attained their peak species richness. However, extrapolations for the two southern areas (Satakunta and Uusimaa) continue to rise, suggesting that there are still many more species to be discovered.

Figure 1 and Figure 2 are essential because it may help us comprehend how many distinct butterfly species exist in the studied regions of Finland. For example, the southern parts of Finland tend to have more species variety than the northern regions, making them more essential to maintain. In Finland, there is a discernible gradient of biodiversity from south to north, with the southern regions containing a greater variety of species than their northern equivalents. This gradient extends from the south to the north. The milder climate, various landscapes, and proximity to the coastline in the south are the origins of this pattern, which is impacted by climatic and environmental factors. These characteristics create favorable conditions for a large variety of species across a variety of habitats. Species richness, on the other hand, is restricted as one proceeds northward due to harsher environmental conditions and a reduction in the diversity of habitats. Boreal forests and tundra are the primary habitats that can be found in this region.

Comparison between the two curves (overall trends comparison of Figure 1 and figure 2): The first curve, which spans the years 1993 through 1997, demonstrates a general upward tendency, with the number of species rising as the sample size of individuals rise. The broad pattern of the second curve (from 2018 to 2022) is similar, although the rate of rise is not as steep. At lower sample levels, the first curve indicates that more species are found in the southern areas (Satakunta and Uusimaa). Although there is less of a difference between the southern and northern areas, the second curve displays a similar trend.Certainly, comparing species richness from 1993-1997 to 2018-2022 demonstrates considerable changes in all regions. The data shows a significant rise in species richness across all regions during the last two decades. This rising trend indicates favorable shifts in biodiversity dynamics across Finland, with a variety of causes likely contributing to this occurrence, including environmental changes, conservation efforts, and habitat restoration activities.

It is crucial to remember that these are just two samples of data; further studies are required to validate this pattern.

4. DISCUSSION

In our study, the comparison of ecological assemblages in Finland between the periods of 1993-1997 and 2018-2022, with a specific focus on observed species (S.obs), sampling completeness index (SC.x), and species accumulation curves, offers useful insights into the changes in butterfly biodiversity over time. These findings provide a substantial contribution to our understanding of the changes occurring in ecological communities and provide valuable information for developing conservation strategies in butterfly habitats in Finland.

Upon analyzing the recorded species counts, it is evident that there have been significant increases in species richness across all regions during the span of two decades. Significant increases in the number of species are specifically noticed in the Keski-Pohjanmaa (KP), Oulun Pohjanmaa (OP), Satakunta (St), and Uusimaa (U) regions. The observed gains indicate a growth in biodiversity, which may be due to favorable changes in ecological dynamics or modifications in the way samples are collected.

Furthermore, the evaluation of sampling completeness using SC.x yields crucial information on the dependability of species assemblage assessments. While several areas exhibit decreases or minor fluctuations in SC.x, other places constantly exhibit elevated values, indicating exceptional levels of sampling. These findings emphasize the significance of using standardized sampling techniques and identify regions that require additional sampling to enhance comprehensiveness. An important aspect of conservation efforts is the ability to identify regional variations in the number of species and the extent to which sampling has been conducted. In general, this information is valuable for determining which areas should be prioritized for protection. Regions that have a decline in sampling completeness, as shown by a decrease in SC.x values, may need specific interventions to increase sample efforts and assure accurate evaluations of species assemblages. Similarly, places that consistently exhibit high SC.x values might serve as templates for implementing successful sampling techniques that can be duplicated in other areas to improve the reliability of data.

An evaluation of estimators, standard errors (s.e.), lower confidence limit and upper confidence limit (LCL and UCL) enhances the analysis by offering insights into trends in species richness and the accuracy of measurements. The constant stability of standard error (s.e.) over different time periods indicates reliable measurement, while variations in LCL and UCL signal changes in the variability of estimates and potential shifts in species richness.

The species accumulation curves from 1993-1997 and 2018-2022 provide graphical depictions of changes in species diversity and sampling effort over time. The graphs depict the first quick discovery of species, followed by a plateau or a slower rate of increase, signifying the point at which species richness becomes saturated. The comparison of the two graphs shows similar broad patterns, with both exhibiting increases in species richness over time, although at varying speeds. The convergence in species richness across the southern and northern regions in the latest dataset indicates that there may be changes in ecological dynamics or habitat conditions that are affecting butterfly populations across Finland. The species accumulation curves provide valuable information about the distribution and saturation of butterfly species diversity in several regions of Finland. The convergence in species richness between the southern and northern regions in the latest dataset indicates possible changes in ecological dynamics or habitat conditions that are affecting butterfly populations throughout the country. This information is extremely helpful for influencing adaptive management techniques and guiding conservation efforts aimed at preserving Finland's unique butterfly species for future generations.

The elevated temperatures and varied ecological systems of the southern regions facilitate a significant degree of species variety. This phenomenon can be ascribed to a diverse array of plant and animal species that have evolved to thrive in certain habitats such as agricultural lands, wetlands, forests, and coastal areas.
In contrast, the northern regions mainly composed of the Arctic tundra supports several species, but the north boreal forests support few species. located farther north exhibit a wide range of species that have successfully adjusted to the frigid climate. The progressive increase in species variety over time, especially as we approach towards the north, highlights the ongoing evolution of ecosystems. This emphasizes the significance of conserving regions with a wide range of various species in the southern areas and acknowledging the importance of diverse communities of species in the northern regions.

Land use patterns and climate variables have a substantial impact on the diversity and distribution of butterflies. Butterfly habitats can be modified by human activities such as agriculture, urbanization, and deforestation. Converting natural habitats into agricultural or urban areas leads to the fragmentation of butterfly habitats, which in turn increases the probability of local extinction. The isolation restricts the mobility of butterflies, which hampers the mixing of genes and increases the likelihood of local extinction. Moreover, the application of pesticides in agriculture can directly jeopardize butterfly populations, affecting their ability to reproduce and ultimately threatening their survival.

Human activities that alter landscapes and weather patterns have a significant impact on butterfly habitats and population dynamics, as these dynamics are strongly driven by changes in land use and climate. This highlights the importance of implementing conservation measures that are specifically designed to align with the distinct attributes of each location.

Furthermore, the increase in the number of different species in the northern regions can be related to the warming climate caused by climate change. This highlights the significance of taking environmental factors into account when assessing biodiversity and implementing conservation measures.

The discovered patterns in the dynamics of butterfly biodiversity highlight the significance of ongoing monitoring and conservation initiatives to save the butterfly habitats in Finland. Additional research is necessary to verify these findings and investigate other factors that affect butterfly biodiversity, such as habitat fragmentation, climate change, and land use practices. In summary, this comparative research establishes a basis for comprehending the intricate dynamics that contribute to shifts in butterfly biodiversity. It also guides specific conservation measures aimed at safeguarding Finland's wide range of butterfly species.

The present investigation complements and enhances the outcomes of Pöyry et al. (2009) and Hällfors et al. (2021). According to Pöyry et al. (2009), there was a notable shift in the average range of Finnish butterflies by over 60 km between 1992–1996 and 2000–2004. This movement was linked to climate change, which emphasizes the need to comprehend the underlying causes behind these changes. The study highlighted the importance of species traits such as mobility, breeding habitat, and larval host plants in determining range changes; non-threatened species expanded their ranges northward, but threatened species did not exhibit any notable adjustments in range.

Similar attention was paid by Hällfors et al. (2021) to the effects of climate change on the boreal Lepidoptera's northward migration. They found evidence of these species migrating northward due to temperature increases. This demonstrates the significant influence of environmental factors on species distribution and emphasizes how crucial it is to take these changes into account when planning conservation efforts.

Furthermore, a recent investigation conducted by Shirey et al. (2021) examined the extent and potential biases in the occurrence data of North American butterflies. Shirey et al. (2021) discovered notable under-sampling in areas undergoing severe climatic change, encompassing many biomes. Their analysis found that community science observations were successfully filling gaps in sampling, with a tendency to select places with greater human presence. In addition, they observed taxonomic biases in both natural history collections and community science data. These findings highlight the need of taking into account possible errors and constraints in data gathering in ecological research.

The utilization of species accumulation curves and sampling completeness indices in our analysis helps mitigate these kinds of biases, resulting in a more precise depiction of species richness and distribution. Nevertheless, like the discoveries made by Shirey et al., it is possible that the Finnish data still exhibits geographical biases. This emphasizes the necessity for ongoing enhancement in data collection techniques and the incorporation of various data sources to guarantee thorough and impartial evaluations of butterfly biodiversity.

Our findings support and enhance the knowledge presented by Pöyry et al. (2009), Hällfors et al. (2021), and Shirey et al. (2021), emphasizing the importance of climate change and species-specific characteristics in influencing changes in biodiversity. These studies substantially improve our comprehension of the dynamics of butterfly distribution and provide valuable information for developing focused conservation measures to reduce the effects of continuing environmental changes on butterfly populations in Finland.

5. CONCLUSION

This dissertation provides insights into the diversity of butterflies in Finland, highlighting differences and changes over time that are essential for effective conservation efforts. In summary, this research offers insights into the diversity of butterflies in Finland. Through the utilization of accumulation curve analyses of data obtained from the Laji.fi database, this study serves to improve our understanding of the ways in which alterations in land use and climate have an impact on butterfly populations. One of the most important discoveries was the identification of diverse butterfly populations in different regions, which highlighted the importance of taking into account regional differences when planning conservation efforts. Furthermore, the assessment of changes has revealed alterations in butterfly populations throughout the course of time, highlighting the dynamic characteristics of biodiversity as well as the significance of constant monitoring and management measures that are adaptable. The results have implications, for conservationists and policymakers by providing information to prioritize conservation efforts and allocate resources to safeguard butterfly species in Finland. Understanding how butterflies adapt to changes can guide conservation strategies to protect biodiversity for generations.

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APPENDIX 1: A Comprehensive Guide to Rarefaction Analysis Using R

```
## these are packages needed to install; they contain the functions one needs
    library(iNEXT)
    library(reshape2)
    library(ggplot2)
    ## this is where one needs to point at the folder with the files. (has to be "/" not "\")
    setwd("G:/Rworkshop")
```

```
# This is to read the file with the data > need to put the correct name of the file
```

```
    data_sp <- read.table(file = "species_bio_province_1993_1997_data.txt", sep = ";", header = T) or data_sp <- read.table(file = "species_bio_province_2018_2022_data.txt", sep = ";", header = T)
```

```
### show the list of regions' name
    unique(data_sp$bio_province)
```

```
# showing the first lines of the data table >> see the names of columns
    head(data_sp)
```

```
### select the regions
    selected_regions <- c("Satakunta (St)", "Uusimaa (U)", "Keski-Pohjanmaa (KP)", "Oulun Pohjanmaa (OP)")
```

```
### Selection of table row corresponding to the selected regions.
```

```
data_sp_selected_regions <- data_sp[data_sp$bio_province %in% selected_regions , ]

################### make rarefaction analysis

data_sp_selected_regions$bio_province <- as.factor(data_sp_selected_regions$bio_province)
data_sp_selected_regions$scientific_display_name <- as.factor(data_sp_selected_regions$scientific_display_name)

# Operation to reshape the data in the format for iNEXT

data_sp_2ways <- recast(data = data_sp_selected_regions, scientific_display_name ~ bio_province, sum)

###### iNext analyses > this takes a long time

rarefaction_bio_province <- iNEXT(data_sp_2ways[, -1], q= 0, datatype = "abundance")

###### rarefaction analysis with endpoint at 95% coverage  > this can also take a long time

estimates_endpoint <- estimateD(data_sp_2ways[, -1], q= 0, datatype = "abundance", base="coverage", level = 0.95)

############################## this section extract and combines the results
### extract the results
## extract species asymptotic estimates

rarefaction_bio_province$AsyEst

AsyEst <- rarefaction_bio_province$AsyEst
```

```
AsyEst2 <- AsyEst[AsyEst$Diversity == "Species richness", ]

ggiNEXT(rarefaction_bio_province)

## extract species coverage at observation level

obs_value <- rarefaction_bio_province$DataInfo

### combine results and save table

results <- merge(obs_value[,c(1:4)], AsyEst2)
results$Diversity <- NULL
results$Observed <- NULL

results <- merge(results, estimates_endpoint, by = "Assemblage")

### Then save the results table in a new file

write.table(results, "results_rarefaction_bioprovince.txt", sep = ";", row.names = F)


#### shows the table of results. look at the description of the iNEXT package to know what the abbreviations mean (column names)
### then one can try to make graphics from this table.

results
```