Museum collections and field monitoring schemes give insight into *Phengaris* butterfly populations and their main distribution in Bavaria (Lepidoptera: Lycaenidae).

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Zusammenfassung: Museumssammlungen und Feldbeobachtungen geben Aufschluss über die *Phengaris*-Populationen und deren Hauptverbreitung in Bayern (Lepidoptera: Lycaenidae).

Schmetterlinge der Gattung *Phengaris* sind bedrohte Graslandspezialisten, die durch die FFH-Richtlinie geschützt sind. In Bayern sind vier Arten heimisch: *P. nausithous*, *P. teleius*, *P. alcon* und *P. arion*. Es wurde untersucht, ob 1) die Anzahl der Nachweise mit der Zeit abnahm; 2) ob die Bundesartenschutzverordnung einen negativen Einfluss auf die Anzahl gesammelter Schmetterlinge hatte; und 3) welche Landkreise über die meisten Nachweise der Arten verfügen. 14364 bayerische Nachweise dieser Arten wurden aus verschiedenen Quellen zusammengetragen. Die Gesamtanzahl aller *Phengaris*-Nachweise sowie der Lebendnachweise nahm zu, während die Anzahl gesammelter Schmetterlinge im Jahr 1969 den Höhepunkt erreichte und anschließend abnahm. Die Bundesartenschutzverordnung 1980 könnte demnach zu verringerter Sammleraktivität geführt haben. Das Sammeln von Schmetterlingen hatte aber scheinbar bereits davor an Attraktivität verloren. Da die Zahl der Gesamtnachweise stetig zunahm, konnte dieser Verlust an Information durch Lebendnachweise mehr als kompensiert werden. In den Landkreisen mit den meisten Nachweisen sollte überprüft werden, ob es sich tatsächlich um Schwerpunktvorkommen handelt, oder ob die Anzahlen der Verteilung der Sammler/Beobachter geschuldet ist.

Key Words: habitat directive, myrmecophilous butterflies, Large Blue, Dusky Large Blue, Scarce Large Blue, Alcon Blue, *Phengaris arion*, *Phengaris nausithous*, *Phengaris teleius*, *Phengaris alcon*

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Introduction

Agricultural land, intensive land use and habitat fragmentation are increasing, causing losses in biodiversity (Tscharntke & al., 2005; Tilman & al., 2020). This can also be observed in Bavaria, where the number and population sizes of butterfly species are declining (Haslberger & Segerer, 2016). In this project, the focus is on the four butterfly species of the genus *Phengaris* native to Bavaria: *Phengaris alcon* ([Denis & Schiffermüller], 1775), *Phengaris arion* (Linnaeus, 1758), *Phengaris nausithous* (Bergsträsser, 1779) and *Phengaris teleius* (Bergsträsser, 1779). *P. nausithous*, *P. teleius* and *P. arion* are protected under the Habitats directive (FFH-Richtlinie, 1992). In the Red List of Bavaria, *P. alcon*, *P. arion* and *P. teleius* are listed as endangered, while *P. nausithous* is listed as near threatened (Voith & al., 2016). They are grassland specialists (Van Swaay & al., 2006), that can be used as indicator and umbrella species for the biodiversity of many grassland species (Randle & al., 2005; Skórka & al., 2005; Thomas & al., 2005; Spitzer & al., 2009). In this project different types of records of *Phengaris* butterflies in Bavaria were compiled and used to investigate these research questions:

1) Did the number of recorded butterflies decline with time?
2) Did the Federal Species Protection Regulation, which took effect in Germany in 1980, have a negative influence on the number of recorded butterflies?
3) What are the five districts in Bavaria with the strongest population records for each *Phengaris* species?

Materials and Methods

To investigate these questions different sources of records of *Phengaris* butterflies found in Bavaria were investigated. These sources included websites, private collections, museum collections from the Naturerlebnis Bruckmühl, the Natural History Museum of Coburg and the Bavarian State Collection for Zoology and ASK records from the Bavarian Environmental Protection Office (LfU). In total 14 364 records were collected.

Records from museum and private collections were summed up as "museal records", while photo records from the internet and records from field monitoring schemes are later called "live records". All records together, as well as museal records and live records separately were analyzed using the statistical program R (R Core Team, 2019). We performed generalized additive models from the package "mgcv" (Wood, 2011) to find out if there is a significant change across the years (Study question 1). For study question 2, we performed a Mann-Whitney-U test, comparing the records of an equal amount of years before and after the Federal Species Protection Regulation took effect. The five districts with the strongest population records were determined by using all records together (Study question 3).

Results

The generalized additive models for the first question revealed a significant correlation between number of records per year and year for all records, live records and museal records (all records: $p < 2 * 10^{-16}$, adjusted $R^2 = 0.529$; live records: $p < 2 * 10^{-16}$, adjusted $R^2 = 0.642$; museal records: $p = 0.0121$, adjusted $R^2 = 0.106$). The number of all records and live records increased with time, while museal records increased until 1969 and declined afterwards.

The Mann-Whitney-U tests for the second question showed, that the number of all records and the number of live records per year was significantly higher after 1980, when the Regulation took effect (all records: $p = 1.305 * 10^{-13}$; live records: $p = 1.773 * 10^{-13}$). The number of museal records per year was significantly lower after 1980 ($p = 0.05037$).

The five districts with the most records of *P. alcon* are Ostallgäu, Weilheim-Schongau, Neumarkt in der Oberpfalz, Garmisch-Partenkirchen and Bad Tölz-Wolfratshausen. The five districts with the most records of *P. arion* are Oberallgäu, Neumarkt in der Oberpfalz, Bayreuth, Bad Tölz-Wolfratshausen and Eichstätt. The five districts with the most records of *P. nausithous* are Main-Spessart, Haßberge, Dingolfing-Landau, Cham and Rhön-Grabfeld. The five districts with the most records of *P. teleius* are Deggendorf, Cham, Weilheim-Schongau, Traunstein and Aschaffenburg.

Discussion

Despite the negative population trends of the four *Phengaris* species (Voith & al., 2016), the number of records in total and of live records is increasing. This increase of records does not reflect a population increase, since they are not from standardized long-term monitoring, but from many different sources. This increase could instead be explained by better monitoring schemes.

Since museal records decreased after the Federal Species Protection Regulation took effect, it seems to have succeeded in limiting the collection of these four butterfly species. But the model for the first question indicates, that the decrease started before that. It could be, that butterfly collecting began to fall out of fashion during that time, as it is not nearly as popular now, as it was in the past. In this project, there was not only an increase of live records, but also of the records in total. This means, that the decrease of museal records was more than compensated for by the increase of live records. Information about the distribution of these butterfly species, therefore, was not negatively affected by the decline of butterfly collecting.

Some of the districts identified for the third question had the highest records for more than one *Phengaris* species. As an example, Neumarkt in der Oberpfalz and Bad Tölz-Wolfratshausen had the highest record numbers for *P. alcon* (Neumarkt: 517 records, Bad Tölz: 320 records) and *P. arion* (Neumarkt: 732 records, Bad Tölz: 388 records). Cham was included in the record-strongest districts of *P. nausithous* (2775 records) and *P. teleius* (1134 records). This could be because these species are closely related and have different but similar habitat requirements (Thomas, 1995; Munguira & Martín, 1999; Schlick-Steiner & al., 2002; Van Swaay & al., 2006; Batáry & al., 2009; Van Swaay & al., 2012; Sanetra & al., 2015). Another possibility is, that these districts might have more near natural or protected areas in general. In fact 6 of the districts included in these Top Five districts are among the 10 Bavarian districts with the largest amount of protected areas (Bayerischer Landtag, 2020). However, one of the districts included in these Top Five districts is actually the district with the smallest amount of protected areas in Bavaria (Bayerischer Landtag, 2020). Finally, also the place of residence and holiday preferences of butterfly collectors might have driven the amount records of these districts. We therefore cannot distinguish real population sizes from mere sampling effects, as our data are not based on a standardized design. As a result, standardized monitorings in the Top Five districts should in the next step evaluate, if there really are suitable habitats with large *Phengaris* populations and if so, how these populations can be best protected.

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