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Planning insect surveys in alpine ecosystems

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Abstract

Most biological survey programs rely on multi-species inventories (e.g. birds, amphibians, butterflies, dragonflies). These programs usually rely on multiple visits during pre-defined time windows. The implicit goal of this popular approach is to maximize the observed species richness. Here, we present a novel method to optimize the timing of survey windows using a framework maximizing the detectable species pool. We present a proof of concept using 20 years of entomological records in Switzerland using butterflies, dragonflies, and grasshoppers. The general framework presented can potentially be applied to a wide range of biological survey schemes. It offers a new practical tool for adaptive entomological monitoring under climate change.

Key Words

Lepidoptera, Odonata, Orthoptera, altitudinal levels, phenology, adaptive monitoring

Introduction

Standing at the core of complex ecological food webs, insects provide insights into the health and stability of ecosystems. They are thus widely used as bioindicators at local, regional, and international scales (McGeogh 1998; Thomas 2005; Buckland and Johnston 2017; Chowdhury et al. 2023). By surveying and monitoring insect diversity, we gain a better understanding of the intricate relationships between species and their habitats across time, enabling us to develop environmentally sound conservation strategies and evaluate the efficiency of public policies (Yoccoz et al. 2001).

Many of the ongoing entomological survey programs aim at estimating species richness among taxa. Even though recent technologies (e.g. computer vision, acoustic monitoring, radar, and molecular methods) offer new perspectives (van Klink et al. 2022), visual encounters remain the most widespread approach. This is especially true for several popular taxa that are widely surveyed in alpine ecosystems, such as butterflies/day-flying moths, dragonflies/damselflies, and crickets/grasshoppers, all of which can be readily identified or photographed in the field. Even though these taxa do not contain an overwhelming number of species compared to other taxa, surveying them remains a costly endeavor.

Entomological visual surveys are usually based on repeated visits across the activity period of the focal taxon. This is necessary because individual species fluctuate in abundance asynchronously during a year (the adult activity or flight periods of various species of insect typically only partly overlap within a focal taxon, see Pellet 2008). These multiple visits aim to maximize the chance of encountering all potentially present species. Monitoring schemes therefore very often rely on pre-defined time windows surveys that are assumed to maximize the observed species richness of the community under scrutiny.

Here, we present a novel approach to identify the best time windows for surveying alpine entomological communities by optimizing the encounter probabilities of every species with as few visits as possible. Using 20 years of observations for three popular taxa, we provide evidence-based, data-driven, guidance for alpine insect survey planning.

Material and methods

We first extracted all observations of Lepidoptera (limited to butterflies and day-flying moths), Odonata (dragonflies and damselflies), and Orthoptera (crickets and grasshoppers) from info fauna, the Swiss biological records center (www.infofauna.ch) for the period spanning 2003–2022. The data was then organized into three matrices (one for each taxon) containing (i) the species name, (ii) the year the observation was made, (iii) the altitudinal levels of the observation, (iv) 52 columns corresponding to the weeks of the calendar year. These weekly columns were then filled with the total number of adult individuals of a given species that had been observed each year at a given altitudinal level.

Species detectability in a given week at a given altitudinal level was first assumed to follow $P(X_{s,t}) \cong 1 - e^{-N_{s,t}}$, where $P(X_{s,t})$ is the probability of detecting species s during week t and $N_{s,t}$ is the number of observations of species s during week t. That is, the more abundant a species is, the more likely it is that a single individual of that species will be observed. In short, we ended up with an expected number of species being potentially observed at every altitudinal level, week, and year.

Our optimization algorithm then worked through the following steps, iterating years and altitudinal levels, finding - by exhaustion of all possibilities - the combination of survey weeks maximizing the sum of $P(X_{s,t})$ (i.e. the number of species likely to be detected). For convenience, we tested 5 scenarios representing an increasing number of annual surveys (from 1 to 5). We then used this data to plot the best time windows - from a single week to a combination of 5 different weeks - that maximize the species richness likely observed by an observer.

The first draft of the introduction, discussion, and abstract of this paper has been adapted with PerplexityAI (2023). Prompts included the first version of the texts along with requests to (i) shorten paragraphs, (ii) improve clarity and (iii) correct any grammatical errors. All outputs from PerplexityAI (2023) were then reviewed and edited before being taken into consideration.

Results

The optimized survey windows for 3 taxa and 3 altitudinal levels are described in Fig. 1. Each of the 9 sub-figures illustrates the best periods to maximize detectable species richness under 5 survey intensity scenarios (from a single annual survey to 5 annual surveys).

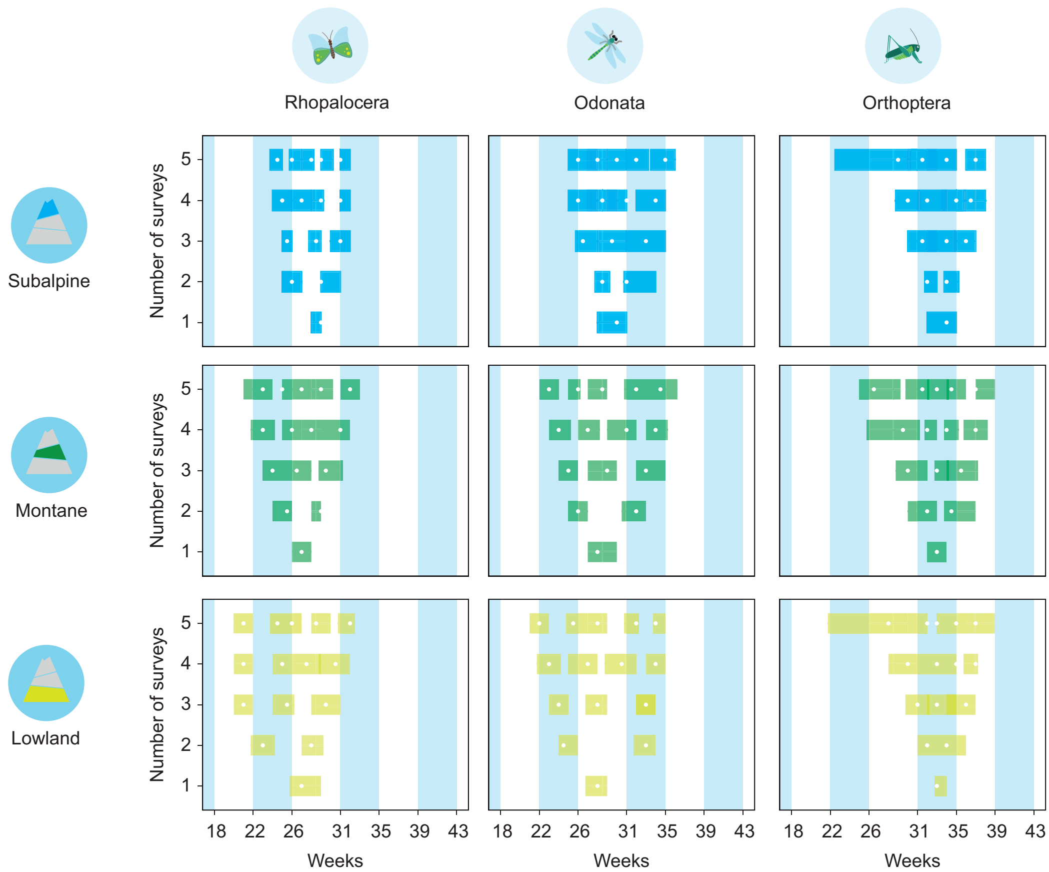

Figure 1. Optimal time windows to maximize potential species richness in entomological surveys for 3 taxa at 3 altitudinal levels assuming between 1 and 5 surveys each. The mean of the 2003–2022 period is represented with a white dot, the colored bars represent the standard deviation. A single survey aiming at maximizing the potential species richness of butterflies in the lowland (lower left sub-figure) would have to take place between weeks 26 and 30 of the year (first half of July). If two surveys are planned, then they should ideally take place on week 23 (early June ±1 week) and on week 28 (mid-July ±2 weeks).

For Odonata at the subalpine level (top middle sub-figure), a single visit should be made on the last week of July (the white dot representing the median best week). Depending on yearly variability, this best week can span anywhere between mid-July and the end of August. If two surveys are envisioned, then the first one should occur in mid-July and the second one in early August.

As expected, higher elevations translate into later survey windows, the amplitude of the shift being about 2 weeks between the lowland and the subalpine levels. Fig. 1 also shows, with little surprise, that Orthoptera tend to be more detectable later in the year than Odonata and Rhopalocera, the latter two groups having a larger spring/early summer species pool.

Running the algorithm for the 1983–2022 period (data not represented in Fig. 1) yielded valuable insights into changes in the timing of the optimal survey windows between the two 20-year periods. On average, all groups showed an advance of the best time windows of 0.9 weeks. That is, the best time windows moved about one week early between the two time periods. More specifically, Rhopalocera and Orthoptera showed a bigger advancement (1.1 week) than Odonata (0.6 week). The advancement of the timing was also larger at the subalpine level (1.6 weeks) than at lower elevations (0.9 and 1.2 week for the lowland and mountain levels respectively). There was, however, no significant change in the standard deviations of the best time windows for any taxon or altitudinal level.

Discussion and conclusion

Insect surveys represent technically and logistically challenging operations that can prove costly (Field et al. 2007). In a world of limited financial resources, optimizing survey periods allows for a better balance of resources between monitoring investments and management actions, which constitute the final aim of most natural resources public policies (Field et al. 2007). This approach requires that the goals and scope of the surveys be explicitly formulated (Anderson 2001). In our case, we postulated, as in many ongoing programs, that maximizing observed species richness was the objective. Maximizing species cumulative detection probabilities across multiple surveys increases the chance of obtaining relevant species community data, as well as identifying species/habitat relationships or detecting trends in occupancy (Pollock et al. 2002; MacKenzie and Royle 2005; Mourguiart et al. 2020). This optimization approach focusing on both detection probability and estimates of occupancy has proven useful in other groups in the past (e.g. amphibians, Barata et al. 2017 or mammals, Baumgardt et al. 2019). In short, our approach potentially increases the return on investment for multiple species survey schemes.

By using a large 20-year-long dataset across multiple altitudinal levels, we closed the loop of active adaptive monitoring, where data collected in the past is used to improve future efforts (Lindenmayer et al. 2011). This is especially important under climate changes that shift both habitat suitability and phenological periods of insects and other cold-blooded species (Vitasse et al. 2021; Buckley 2022). As we have shown here, the overall phenological shift in 20 years is about 1 week. It is consequently a necessity to regularly adapt existing survey programs (Halsch et al. 2021; Hill et al. 2021). Further optimization could consider not only changes in emergence timing but also changes in voltinism or shifts in altitudinal ranges.

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