Insect Monitoring Techniques: Evaluating Comparisons and Beyond

Quantification of the differences between insect monitoring techniques with respect to insect abundance and species composition

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Abstract

Insect monitoring techniques help to understand how insects are in decline. This is done by studying species richness, abundance, composition, biomass and temporal dynamics in response to environmental changes. Due to the increasing use of insect monitoring techniques together with maintaining relevant monitoring data for trend analyses, sampling methods should be standardized, and biases should be addressed. However, this is not always done correctly. The aim of this essay was to critically evaluate studies that performed quantitative comparisons among different insect monitoring techniques, focusing on insect abundance and species composition. From thirteen quantitative literature and from the eight qualitative studies, it can be concluded that most existing literature did not show how trap design influence trap catch, rather it explained potential biases that influences the results and the considerations of factors such as cost and time efficiency. It is essential to recognize how these design factors specifically impact variations in trapped species in combination with addressing biases in species composition and abundance for meaningful insect trend analysis. Once this is well-described, a clear understanding emerges regarding insects captured by particular techniques and how multiple techniques, alongside in the field can complement each other regarding species composition, insect abundance and biomass. Eventually data can be shared and combined to enhance knowledge of insect diversity, abundance, species composition, and biomass trends over time in specific sites/ecosystems.

1. Introduction

Insects experience a 75% decline because of anthropogenic influences (Hallmann et al. 2017). For instance, with the expansion of infrastructure and urbanization and the intensification of agriculture, natural vegetation has been reduced and transformed into intensively managed landscapes (IPBES 2019), leading to a decrease in habitat for insects. Additionally, the widespread use of pesticides, particularly insecticides, also contribute to the decline of insect populations, impacting, for instance, bumblebees (Marletto et al. 2003). The decline of insects is concerning due to their crucial role in ecosystem functioning (Potts et al. 2010), and provision of essential ecosystem services, such as pollination that is needed for flower reproduction (Ponisio et al. 2017).

To understand the extent of insect decline, studies have been conducted on insect trends. However, obtaining comprehensive data on insect trends remains challenging (Potts et al. 2016; van der Sluis 2020). That is why it is essential for conservation efforts to recognize how insects respond to environmental changes (van Klink et al. 2022). This understanding is facilitated through insect monitoring techniques (Saunders et al. 2020). Insect monitoring aims to research not only species richness, abundance, composition, and biomass (Hausmann et al. 2020), but also the dynamic temporal aspects of insect populations (Portman et al. 2020). This includes investigating how species decline in abundance over time and understanding their ecological interactions (Portman et al. 2020). These interactions are important for understanding how an ecosystem functions and how insects will respond to habitat changes (Ogilvie & Forrest 2017). However, these aspects present significant challenges in research (Osborn et al. 2022). Addressing these complexities is vital for formulating conservation strategies to conserve insect biodiversity.

Monitoring techniques are in an increasing use and can vary in many ways. Passive collection methods effectively obtain specimens with temporal and geographical data (Darling & Packer 1988). For instance, Malaise and Möricke (pan/bowl) traps are extensively employed for collecting Diptera and Hymenoptera (Aguiar & Santos 2009; Karlsson et al. 2020). Within Malaise traps design itself, a variety in, for instance, mesh size can already affect species composition. For example, a fine mesh collects more Ichneumonidae, while a coarse mesh collects more Aculeata species (Darling & Packer 1988). Another monitoring techniques are pan traps and can vary in bowl colour, attracting different species based on light wavelength (Darling & Packer 1988). Pitfall traps are appropriate for ground-dwelling insects such as beetles (Carabidae and Staphylinidae), ants and spiders (Skvarla et al. 2014). Various other lethal passive traps exist, but monitoring can also be conducted without killing insects. This includes light trapping for phototactic night-flying insects, acoustic monitoring for cicada and crickets, active visual surveys primarily focused on larger insect species, such as butterflies and bumblebees (Montgomery et al. 2021), and smart insect cameras for automatic insect recognition (Hogeweg et al. 2019; van Klink et al. 2022).

Efforts to quantify insect trends also encounter obstacles such as gaps in data and knowledge concerning the status, trends and drivers of insect population change (Potts et al. 2016). These challenges arise by the non-comparability of studies (Uhler et al. 2022), contributing to the existing limitation in understanding insect dynamics. Systematic, long-term monitoring of insect abundance and diversity is often lacking (Montgomery et al. 2021). Additionally, insect monitoring is predominantly localized in Europe (Saunders et al. 2020). Moreover, studying insects itself is challenging (Osborn et al. 2022), due to their diversity (Stork 2018), small size, high abundance, long-distance dispersal capability, relatively short life span, and abundance fluctuations across years (Osborn

et al. 2022; van Klink et al. 2022). The identification process is additionally hindered by the lack of an attractiveness level and the necessity for taxonomic specialists, who often focus on insect distribution.

Furthermore, comprehensive reviews on (other) specific insect monitoring traps (Aguiar & Santos 2009; Skvarla et al. 2021) or trapping efficiency (Darling & Packer 1988) are lacking. Recent reviews emphasize the insufficiency of relying on a single technique, advocating for the combination of quantitative and qualitative methods to ensure comprehensive data on species richness, abundance, and composition (Russo et al. 2011; Hausmann et al. 2020; van Klink et al. 2020; Uhler et al. 2022; van Klink et al. 2022). Combining techniques, such as Malaise traps and light trapping, along with DNA metabarcoding will enhance species identification richness (Hausmann et al. 2020). Or combining malaise traps with other traps with least overlap in taxa trapping, for instance with pitfall traps, can maximize the trapped insect diversity with less effort (Skvarla et al. 2021). On top of that, integrating data globally contributes to understanding insect decline, but challenges, such as geographic and taxonomic restrictions, persists (Saunders et al. 2020).

Standardizing sampling methods and addressing biases are crucial to maintain the relevance of monitoring data (Saunders et al. 2020). It will ensure that monitoring efforts can continue meaningfully to more knowledge on insect populations over time. A few studies delve into the consequences of trap choice for the quantification of insect abundance and species composition. For instance, Aguiar & Santos (2010) describe how Möricke and Malaise traps differ from each other in collecting Hymenoptera, while location and abiotic conditions are equal. Meanwhile, various reviews evaluate insect monitoring techniques based on factors like cost, field practicality, and data yield. For instance, Darling & Packer (1988) evaluate the influence of Malaise trap design, mesh size and location in collecting Hymenoptera. Rather than repeating these well-explored comparisons in trap design, this literature study focuses on how the quantification in the differences between insect monitoring techniques should be done with respect to insect abundance and species composition.

The aim of this study is to fill this critical gap by critically assessing how monitoring techniques should be compared with the objective to combine data from different trap types in an overall trend analysis. This review compares insect monitoring techniques in insect collection. The intent is not merely to describe these comparisons, but to lay the groundwork for a more comprehensive understanding of how monitoring techniques perform in diverse ecological settings and as a result how trend analyses can be performed based on diverse datasets. These recommendations can be taken into account in a practical application when comparing insect monitoring techniques. A start has been made to set up an analysis for DIOPSIS (Digital Identification of Photographically Sampled Insect Species) camera data and to compare it with the, alongside, traditional passive traps (Malaise and pitfall traps). These comparative analyses, conducted at the same locations with identical abiotic conditions, seeks to unveil the performance of DIOPSIS cameras in insect monitoring, contributing to valuable insights to the broader scientific community.

2. Literature assessment of insect monitoring techniques

To quantify differences in insect abundance and species composition through different insect monitoring techniques, I critically assessed the advantages and disadvantages of comparing such techniques from existing literature (section 2.1). Following this, I evaluated how insect monitoring techniques are compared in the literature and identified the underlying criteria for these comparisons (section 2.2). Subsequently, I provided recommendations for conducting comparisons to meet the requirements of trend analysis research (section 2.3). This is because there is a lack of standardization in insect monitoring techniques, leading that data cannot be combined, failing its ecological potential or conservation needs (Montgomery et al. 2021).

2.1 Advantages of specific ways of comparing insect monitoring techniques

Various insect monitoring techniques are compared in the literature, as these monitoring techniques are increasingly in use due to the decline in insect populations. Comparisons in monitoring techniques are informative as all information can be found in one place, leading to a better understanding of the sampling techniques. For instance, a better decision can be made which monitoring technique will suit the best according to the research question and the possibilities within the project. Most of the comparisons in insect monitoring techniques are based on costs, trap detectability in the field, and variations in design within the trap itself (Aguiar & Santos, 2009; Gibb et al. 2019; Montgomery et al. 2021). For instance, Malaise traps can vary in mesh and trap size, or pan traps can vary in bowl colour (e.g. Montgomery et al. 2021). Differing in design or setup can already affect the species community that will be trapped (Uhler et al. 2022). For instance, Darling & Packer (1988) concluded that using a coarse mesh size in Malaise traps, that were constructed with leno weave polyester netting with rectangular openings of 0.88 mm effectively captured more Aculeata species, while fine mesh size, that were constructed with tricot warp knit polyester netting with an opening of 0.88 mm, collected more microhymenoptera species. These comparisons based on quantitative work provide insight in species composition and abundance (Montgomery et al., 2021), eventually leading to recommendations about how the trap can be used in a more efficient way (Skvarla et al. 2021). These comparisons are valuable for acquiring fundamental knowledge and research innovation (Gibb et al. 2019). It will lead to a better decision for further research to choose the monitoring techniques that suits the requirements. Table 1 shows, for each quantitative or qualitative study, what the strengths and weaknesses are of comparing insect monitoring aspects. In this way, it is clearer what is still missing for fundamental knowledge and research innovations.

Comparing insect monitoring techniques will also provide insight in what is missing in the literature. For instance, most literature does not discuss which variable, such as mesh size, colour and/or trap size, is responsible for the collected insect species (Table 1). As a variation can already affect the collection of species (McCravy 2018). For example, Montgomery et al. (2021) gives information of trap design, while Darling & Packer (1988) and Uhler et al. (2022) look into the effect of mesh and trap size with trap location on genera collection and species composition. Also, Malaise traps capture mostly Diptera (75%) and Hymenoptera (15%) species, but the families are so diverse that non-targeted insects also get killed (Karlsson et al. 2020; Skvarla et al. 2021). Or pitfall traps capture ground-dwelling insects, which means that beetles, ants and/or spiders get trapped (Skvarla et al. 2014), even if the specific interest is solely beetles. Another consequence of the taxon-non specificity of many trap types is that it can be labour and resource intensive to process the samples. Especially, taxonomic specialists are required when identifying all insects, which also leads to higher costs (Montgomery et al. 2021).

Furthermore, a huge (by)catch often means that a lot of insects will not be identified on species level (van Klink et al. 2022). This means that there is no gain in knowledge about rarer species and that this insect monitoring techniques can harm rarer individuals and populations (Montgomery et al. 2021).

Understanding the advantages and disadvantages of a monitoring technique, along with the knowledge about the captured insect species, a combination of different techniques can be used. This approach will provide valuable insight into population dynamics, distribution, and diversity (McCravy 2018). For instance, employing various passive collecting methods together with pitfall traps, will result in capturing a diverse range of insect species (Russo et al. 2011; McCravy 2018). This approach can also reveal undetected species that may have limited detectability (Amarathunga et al. 2021) through other monitoring techniques. For instance, Malaise traps also capture small bee species that would be missed with bowl traps (McCravy 2018). Moreover, most methods can also be influenced by potential migrants (McCravy 2018), influencing the absolute insect abundance in the location. By comparing the monitoring techniques, we know that emergence traps collect insects in the discrete area rather than collecting potential migrants (McCravy 2018). This provides insights in insect abundance and species composition in the targeted locations (McCravy 2018).

However, a comprehensive understanding of how different monitoring techniques function in targeting specific insect species and how monitoring techniques can complement each other, is currently lacking (Gibb et al. 2019; van Klink et al. 2022). For example, comparing techniques based on a single proxy, such as species richness, abundance, composition, or biomass alone, does not consider all parameters simultaneously (Hausmann et al. 2020). The inclusion of too many proxies, as seen in the case of Malaise traps, which is widely used and trap numerous insects, may be always align with the goal of optimal data collection. Thus, it is essential to compare insect monitoring techniques systematically to evaluate which methods capture specific insects, facilitating a thoughtful experimental design that minimizes unnecessary data collection, thereby reducing costs and time and increasing a range of benefits.

Combining monitoring techniques will allow the status of landscapes and represents a suitable setup for large-scale long-term insect monitoring (Hausmann et al. 2020). It will also provide more information and greater insight than does one single method (Russo et al. 2011; McCravy 2018). For instance, it will increase the spatial, temporal, or taxonomical coverage or a broader range of biodiversity metrics (van Klink et al. 2022). To do this, the advantages and disadvantages of each insect monitoring technique should be clear as each technique has its own strengths and weaknesses (van Klink et al. 2022). For instance, Malaise traps collect Diptera and Hymenoptera (Skvarla et al. 2021). When combining this with other traps that have the least overlap with Malaise traps, such as pitfall traps and leaf litter extraction, it will give a greater abundance and species richness for the study (Skvarla et al. 2021). Furthermore, the use of different trap types and colours could increase, for instance, the proportion of the bee species richness (McCravy 2018). Quantitative studies can also be combined with qualitative studies, together with DNA metabarcoding (Hausmann et al. 2019). This will give information about insect trends, abundance, species composition (Hausmann et al. 2019) and biomass (van Klink et al. 2022).

However, to be able to combine insect monitoring techniques and it gathered data, the challenges lie in the lack of uniform methodology across studies and the limited sharing of data among universities (Skvarla et al. 2021). This combination of data can eventually lead to comprehensive conclusions about insect diversity, abundances, composition and biomass trends over time.

Table 1. An overview of used studies on comparisons of insect monitoring techniques. The most important strengths and weaknesses that emerged when comparing insect monitoring techniques from the literature are summarized.

Reference	Quantitative / Qualitative	Comparison based on	Strengths	Weaknesses
Aguiar & Santos 2009	Quantitative	Malaise and Möricke traps and its taxonomic and sexual differences.	- Malaise and Möricke traps are not linear comparable. - Size, design and mesh size modify effectiveness in trap catch. - Möricke traps are easy to set. - Complement Möricke with Malaise and v.v. for sampling Cryptini in Hymenoptera.	- Sampling of both traps should happen at once to minimize biases in data interpretation. - The reason behind why Malaise traps more flying insects that are negatively geotropic and Möricke traps more Hymenoptera families are unknown.
Amarathunga et al. 2021	Quantitative /Qualitative	Image based insect identification and its targeted insect species, geographic location and image capture methods differences.	- Image-based systems can replace much of human labour work. - The analyses of classification methods show a trend toward applying deep learning techniques for insect identification.	- Few species are covered which limits insect detection and classification. - Only a few studies available. - Mostly based on pests and few on bee and predatory species. - Localized in China, USA, and Brazil. - Photographing active, fast-moving insects is challenging. - Deep learning models needed.
Campbell & Hanula 2007	Quantitative	The effect of Malaise trap design and pan trap colours on insect abundance and diversity.	- Different pollinators groups preferred different pan trap colours. - Colour in Malaise traps influences insect pollinator catches. - Pan traps are low in cost and the use of multiple colours makes it easier method to sample the relative abundance and species richness of pollinators.	- Colour use in Malaise traps are ineffective in capturing Hymenoptera. - Trap catch similarity varies among locations, duration and trap height and the reason behind is unclear.
Darling & Packer 1988	Quantitative	Trap design, mesh size and location of Malaise and pan traps and its effect on number of individuals	- Mesh size and trap type results in different genera collection. - Trap location was unimportant for species composition.	- Unknown which variable (colour, mesh size, air fly, insect flyways, solar path, weather, habitat variability) is responsible for the variability in catch.

		and species composition.	- Pan traps are important component of an efficient Malaise trap.	
Droege et al. 2010	Quantitative	The effect of arrangement and spacing of bowl traps on capture rate.	- Capture rates are unaffected with closely placed bowls.	- Bowl traps need to be closely placed to each other (3-5m) to have a high catchment rate.
Hausmann et al. 2019	Quantitative /qualitative	Malaise traps and automated and active light trapping and its insect diversity, biomass and abundance of taxa differences.	- Combination of quantitative and qualitative studies with DNA metabarcoding will improve the study into insect trends, abundance and composition. - Categorizing individuals based on ecological traits and endangerment will give more inside into landscape status. - Qualitative approach gives information on species abundance and the structure and quality of a species community.	- The number of species and the amount of biomass provides little information on the status of an ecosystem or entire landscape. - Sampling happens taxonomically selective. - Mostly focused on one proxy instead of all parameters in parallel.
Jonason et al. 2014	Quantitative	The influence of weather, time of year, and light source on nocturnal moths with the use of light traps.	- Understanding moths' phenology will increase the trap catch and reduce the influence of abiotic factors.	- Species richness and abundance were influenced by night temperature, humidity and lamp type (wavelength and brightness). - Sample nights affects capture size. - It is difficult to compare moth data as data is sometimes collect at intervals, only on warm nights, and sometimes irrespective of temperature.
Karlsson et al. 2020	Qualitative	Malaise traps and its taxonomic composition and abundance.	- Metabarcoding with high-throughput sequencing generates lists of BINs for a sample and will give more specific data.	- Species composition is rare when utilizing Malaise traps. - It is unknown how representative metabarcoding is for species composition. - Many studies analyse results to a certain level that the BINs allow but no further, which limits the usefulness of such efforts.

Leong & Thorp 1999	Quantitative	The effect of colour use with pan traps on captured bee species.	- Pan traps efficiently and selectively sample bee species associated with *Limnanthes douglasii rosea*.	- Females and males have different colour preferences. - Quantitative bee sampling can be highly sensitive to trap colour.
McCravy 2018	Qualitative	Differences in taxonomy, selectivity, costs, labour with the use of bowl-, vane-, Malaise-, pitfall traps and netting.	- Each sampling method that its advantage and limitations and produce bycatch. - Consistency is essential for comparability. - Combining techniques gives more results than a single method.	- Excessive lethal sampling. - Identification is challenging and time consuming.
Montgomery et al. 2021	Quantitative	Malaise-, light-, pan-, pitfall traps, beating sheets, acoustic monitoring and visual surveys.	- Long-term monitoring is needed to understand insect decline to minimize data gaps. - Methods should be documented carefully and consistent over time to control and estimate biases.	- Monitoring is geographical and taxonomical limited. - Monitoring in sites with rare and endangered species need unique considerations.
Noyes 1989	Quantitative	Sweep-netting, Malaise trapping, yellow pan trapping, flight intercept trapping and canopy fogging and its effect on its efficiency (sample size and number of species collected)	- Malaise traps are most effective in most habitats. - Sweeping was the most effective single method of sampling.	- Yellow pan traps showed different results in trapped species over the locations. - Trap visibility might have an effect on trapped species.
Portman et al. 2020	Qualitative	Drawbacks of bowl traps on monitoring insect abundance and species composition.	- The drawbacks give a good inside in all the variable to think about to have a good experiment with minimal biases.	- They are cheap, simple to use and reduce researcher's biases. - Observed and actual abundance of bees is unknown. - Pan traps collect a filtered version of bee fauna.

				- Unknown if pan traps collect more bees when there are no/many flowers. - Pan traps do not have a lot of historical data and thus difficult to compare monitoring data. - Netting and non-lethal observations are labour intensive and can be influence by the experience of the observer. - All have taxonomic biases and unknown effects of the surrounding. -
Russo et al. 2011	Quantitative	The effect of design, construction, and effectiveness of the Composite Insect Trap and its taxa collection.	- It combines cone-, Malaise-, pan, and flight intercept traps. - It is affordable, easy and collects a wide variety of insects rather than using multiple monitoring techniques in the same location.	- Still lethal monitoring. - Data cannot be compared to single monitoring methods as this techniques combines multiple techniques in ones and can still affect trap catch.
Saunders et al. 2020	Qualitative	Summary of research, communication, and policy priorities for evidence-based insect conservation and insect population dynamics.	- Coordinated monitoring systems that collect standardized observations on multiple taxonomic orders across consecutive years are extremely valuable for identifying temporal patterns in insect populations but are not the only priority for understanding global insect diversity.	- Most studies analyse time periods rather than over time. - Time periods are a poor proxy for environmental change and can overlook correlations within the dataset. - Confirmed declines for taxonomic group in one location do not always translate to other regions or similar species. - Confusing and inaccurate science communication could have counterproductive effects on public support for insect conservation. - Studies are geographically and taxonomically limited.

				- Biases in sampling and analytical methods limits the relevance of studies in insect decline.
Skvarla et al. 2022	Quantitative /qualitative	Trap design and placement of malaise and canopy traps and its effect on trap catch.	- Bycatch give inside into patterns of abundance, distribution and diversity, but also new invasive species.	- Traps get easily damaged. - Targets a lot of species and bycatch, which makes it time consuming. - Impossible to collect in a small area.
Uhler et al. 2022	Quantitative	Size, shape and colour of malaise (Townes vs. Bartak) traps and its effect on biomass, species richness and composition.	- Size does not matter with biomass. - Higher Townes traps catch more mobile flying insects. - White roofs catch more pollinator taxa and easy to recognize in the field. - Bartak are easier to carry and setup.	- Region, habitat, and sampling had more effect on species composition than trap type. - Ethanol in ecletor capture bottle will evaporate faster. - Trap type needs to be selected to fit the research question. - Data should be corrected when comparing different trap types.
Van Klink et al. 2022	Qualitative	Advantages, current limitation and future potential of computer vision, acoustic monitoring, radar and molecular methods	- New/automated monitoring saves time on species identification. - Non-lethal. - Traditional monitoring should be maintained for historic time-series and complement the new technologies. - Large-scale insect monitoring should be collaborated across borders, projects and technologies.	- With traditional monitoring, only a fraction can be identified. - New technologies cannot replace specialists' taxonomic knowledge.

2.2 Comparisons of insect monitoring techniques in the literature

In this section, I evaluated how an insect monitoring technique is compared in the literature. I focused on Malaise traps, Möricke traps, pitfall traps, active light trapping, visual monitoring, netting, and imaged based insect identification separately as these methods are commonly used for both lethal and non-lethal monitoring. This evaluation is valuable to know as most studies focus on differences in trap types based on cost and time efficiency. Indeed, this is to some extent valuable to know, but knowing how comparisons between traps can be made is more important. For instance, knowing how a variation in the trap itself influences insect abundance and species composition because a difference in mesh size in Malaise traps can already influence the captured species composition and biomass (Aguiar & Santos 2009). I also identified the underlying criteria for comparisons in insect monitoring techniques.

Malaise traps

Malaise trapping serves as a method for capturing a diverse array of flying insects especially Diptera and Hymenoptera (Matthews & Matthews 1970; Darling & Packer 1988; Noyes 1989; Karlsson et al. 2020), but also flies, wasps, flying ants, bees, bugs, moths, and semi-aquatic taxa (Matthews & Matthews 1970). Within these groups, it proves especially suitable for capturing Tenthredinidae, Ichneumonidae, Scelionidae, Mymaridae, and other hymenopterans with similar life histories (Montgomery et al. 2021). Additionally, it is effective for Cicadellidae and Cercopidae (Hemiptera), microlepidopterans (Lepidoptera), and semi-aquatic orders such as Plecoptera, Ephemeroptera, and Trichoptera (Montgomery et al. 2021). It is also known that the greatest bee abundance and species richness can be captured in tall grass prairie compared to deciduous forests (McCravy 2018) or a higher trap rate of Lepidoptera in organic farmland compared to conventional farming (Hausmann et al. 2020).

The influence of factors such as colour, mesh size, and location on the capture rate of certain insect groups is well-known (McCravy 2018). For example, Darling & Packer (1988) found that a coarse mesh size is more effective for Aculeata species, while a fine mesh size is preferable for microhymentoperan species. Uhler et al. (2022) demonstrated that variation in size, shape and colour affect biomass, species richness, and composition when comparing Townes and Bartak Malaise traps.

However, the specific design variation causing differences in trapped species remains unclear. Many studies do not explicitly identify the variation that impact the output, such as the taxonomic and sexual biases observed in Malaise traps (Aguiar & Santos 2009). For instance, their tendency to capture more polylectic bees, or their ability to collect the greatest numbers of parasitoids and species richness compared to pan traps (McCravy 2018).

Literature mostly recommends complementing Malaise traps with other passive sampling methods (e.g. Aguiar & Santos 2009; Skvarla et al. 2021). For instance, Aguiar & Santos (2009) propose complementing Malaise traps with Möricke traps, as this combination yields a more diverse array of insect species. Hausmann et al. (2020) recommend a combination of quantitative with qualitative research for more data on biomass and species richness. While it is possible to combine multiple techniques, the question arises: if subtle modification, such as changes in mesh size or trap size, can already influence species composition, is it justified to invest in additional monitoring techniques? Malaise traps are already costly and demand substantial working hours for sample separation and identification (Aguiar & Santos 2009; Montgomery et al. 2021).

Möricke traps

In addition to Malaise traps, Möricke/bowl/pan traps are widely employed, particularly for the collection of Hymenoptera families, with a primary focus on sampling bees (Droege et al. 2010; McCravy 2018). This monitoring technique allows for the estimation of bee abundance, composition, and richness at specific location (McCravy 2018). Bowl traps are commonly favoured due to their cost-effectiveness and ease to setup, making them a practical choice (Aguiar & Santos 2009). For example, deploying multiple pan traps with various colours in a location enables the sampling of relative abundance and species richness of pollinators (Campbell & Hanula 2007). They also do not require collector experience (McCravy 2018).

While this approach may seem advantageous for research, it comes with several taxonomic and sexual biases (Aguiar & Santos 2009). For instance, bowls tend to predominantly attract Halictid bee species (Droege et al. 2010; McCravy 2018), while the effectiveness for other small bee species is unclear (McCravy 2018). Furthermore, the colour and the height of the bowls can selectively attract specific taxa of bees (McCravy 2018), resulting in samples that are under-represented for taxonomic studies and biased outcomes in terms of species richness (Aguiar & Santos 2009), abundance, composition and biomass. Likewise, the colour of the bowl also influences the attraction of females or males (Leong & Thorp 1999).

That is why it is often advised to utilize a combination of blue, white, and yellow bowls to ensure the collection of a diverse range of bee species (Leong & Thorp 1999; Campbell & Hanula 2007). For instance, it has been observed that that Buprestidae, especially *Acmaeodera spp*. are attracted to the blue and white pan traps (Campbell & Hanula 2007), while yellow pan traps attract more Proctotrupiade, Ceraphoronoidae, Chalcidoidae and Aculeata species (Noyes 1989). Compared to Malaise traps, pan traps provide a more detailed understanding of the species captured when varying colours of the bowls.

Pitfall traps

Pitfall traps, which are the third widely used insect monitoring technique, differ from Malaise traps and pan traps. They sample diverse arthropod groups (but see Skvarla et al. 2014), but particularly ground dwelling Aranea and Coleoptera (especially Carabidae and Staphylinidae) have been the most studied ones (Westberg 1977; Skvarla et al. 2014; McCravy 2018).

Despite their versatility, pitfall traps present uncertainties regarding the impact of trap variations on specific species. Factors such as specimen activity levels, abundance, trap coverage, bait usage, surrounding vegetation, and trap shape contribute to variation in the trapped taxa, often favouring larger-bodies species (McCravy 2018; Skvarla et al. 2014). Consequently, pitfall traps do not precisely reflect the absolute density of sampled organisms (Skvarla et al. 2014), making them less suitable for trend analysis.

Despite these disadvantages in researching species richness and composition, it is generally recommended to combine passive monitoring techniques with pitfall traps (McCravy 2018). Notably, the variation in pitfall traps for species inventory studies can enhance their effectiveness in capturing greater combined species richness (McCravy 2018). If not, trap design should be consistent (McCravy 2018) to be able to combine datasets.

(Active) light trapping / visual monitoring

Active light trapping and visual monitoring serve as common methods for documenting insect abundance and diversity, focusing on species that are easily identifiable and countable in the field (Montgomery et al. 2021). Light trapping specifically targets nocturnal flying insects, attracting Diptera, Hemiptera, Coleoptera, Trichoptera, Hymenoptera and Lepidoptera (Montgomery et al. 2021). In contrast, visual monitoring, suitable for large insects that are easily detectable in the field, lacks specificity in taxa identification, leading to a considerable underestimation of unseen or challenging-to-identify insects (Montgomery et al. 2021). Detailed information, including location, time intervals, temperature, transect length, etc., are crucial as it influences insect presence. Light survey parameters, such as wavelength and brightness, play a significant role in species attraction at night (Jonason 2014). These techniques are mostly repeated to mitigate abiotic effects, making sure that it will not be a new observation but rather a repetition. In this way, year to year can be compared for the diversity of the community (Montgomery et al. 2021).

In contrast to other traps, these monitoring techniques are particularly suited for citizen science, facilitating extensive data collection on species abundance and composition, thereby contributing to valuable insights for trend analyses. The data collection citizen science primarily encompasses larger insects, unless volunteers possess specialized knowledge in specific groups, thereby expanding the potential for trend analyses, especially for less-known species. As it is citizen science, it is essential to acknowledge potential variability in data quality due to variations in participants' skills. Therefore, the availability of a clear protocol and survey form, ensuring the inclusion of influential factors like temperature and date, is important for accurate insect monitoring in citizen since projects.

Netting

Netting is a commonly used monitoring techniques to collect arthropods on vegetation and provides a relatively complete sample of the bee fauna present (McCravy 2018). Within this monitoring technique, targeted netting and sweep netting can be performed (McCravy 2018). Whereas with targeted netting it is possible to collect particular species and associate the individual bee with the particular flower it was visiting, while sweep netting provides information of relatively small or inconspicuous bees that may not be collected readily by targeted netting (McCravy 2018).

Both has its advantages and disadvantages. For instance, it yields a large amount of specimens, and can be relatively complete for the bee fauna that is present on the location (McCravy 2018). It can also target fast-flying bee species such as *Colletes*, *Megachile* and *Melissodes* (Giles & Ascher 2006) and it is inexpensive (McCravy 2018). However, this method is labour-intensive, subjected to variation in collector abilities, and may not fully capture the factors influencing catches (McCravy 2018).

Netting does not capture all insect species on the location, thus not providing the species abundance and composition. That is why it is recommended to complement netting with other monitoring techniques, such as blue vane traps (McCravy 2018). While sweep netting can supplement bee samples collected by other methods, the variations in technique execution and potential biases underscore the importance of a nuanced and reflective approach in interpreting the data obtained. Efforts should focus not just on what is caught but also on understanding how and what influences the outcomes of sweep netting to enhance the reliability and comprehensiveness of the collected data.

Image-based insect identification

Image-based insect identification is quite a new technology that arose from wanting to decrease the workforce amount (Martineau et al. 2017; van Klink et al. 2022). It has the potential to increase the spatial, temporal and taxonomic coverage of monitoring programmes (van Klink et al. 2022). In this way, it can give more information about species' occurrence, abundances, individual size, biomass and movement (Bruijning et al. 2018; Schneider et al. 2022) compared to passive monitoring.

As computer vision advances with algorithms for automated species identification from digital images, offering the potential for live and dead insect counting while minimizing human labour and observer bias, it also confronts certain limitations (van Klink et al. 2022). Such as, that it needs a substantial amount of trainings data that also needs to be identified to species level via entomologists (van Klink et al. 2022). Additionally, certain species poses challenges for detection and classification due to restricted classified objects (van Klink et al. 2022), particularly those deemed rare or unknown species (Amarathunga et al. 2021). This emphasizes the importance of considering variations in species and geographic locations in research (Amarathunga et al. 2021). Furthermore, photographing active, fast-moving insects remains a formidable task (Amarathunga et a. 2021) and the algorithm has difficulties in identifying certain objects like black screens or vegetation obstructing the camera against a yellow screen.

While computer vision offers exciting opportunities for automating insect observations and classification, understanding and addressing these biases and limitations are crucial for its effective and reliable implementation in scientific research. When using only image-based insect identification, it is possible that not all insects can or will be identified into species level and thus species composition is lacking. On top of that, the same as with pan traps, a yellow screen is mostly used and thus can lead to specific species that can be attracted to this screen. Even though, other colours are possible, identification with another coloured screens seem to be still difficult (RWR Strik, personal communication, 23 November 2023).

2.3 Recommendations to improve comparative studies

I proposed several recommendations for each insect monitoring technique to improve such comparison studies. To be able to use these recommendations for the case study (section 3) a concise summary is provided below.

At first, it is important to explain the reason behind choosing or having used a particular monitoring method for the research, considering factors such as cost, time efficiency but also trap design variations. This understanding is crucial for recognizing biases and potential influences on the collected data. It will also minimize unnecessary data collection. Secondly, it is important to notate how these design factors specifically impact the variations in trapped species, addressing the variations in species composition and abundance. In this way, it is not directly necessary to choose another monitoring technique for trapping other insect species.

As species identification can be time-consuming and are frequently only identified on family or genus level, a new technology offers a promising solution: DIOPSIS (Digital Identification of Photographically Sampled Insect Species). This technology employs an algorithm for insect identification, providing information on species abundance, composition and biomass without lethal sampling. As a result, it enables data collection without the necessity for manual identification efforts.

Once the impact of trap variations on trap catch are documented in the literature, a combination of monitoring techniques will improve insect trend analysis. For instance, combining various monitoring techniques can show more insight into population dynamics, distribution, and diversity. Furthermore, citizen science contributes to expanding datasets for trend analysis. The only limitation is that mostly large insects are observed and identified, unless volunteers specialize in specific groups, or a passive monitoring trap can be used.

Finally, when the advantages and disadvantages of insect monitoring techniques are well described, data can be shared and combined. In this way there is an increase in knowledge of insect diversity, abundance, species composition and biomass trends over time at particular sites/ecosystems.

3. Case Study set-up: performance of DIOPSIS cameras

Fieldwork is already done to be able to compare how DIOPSIS cameras perform in identifying insect species, insect abundance, species composition and biomass compared to, the alongside, Malaise and pitfall traps. These comparative analyses, conducted at the same location with identical abiotic conditions, seeks to unveil the performance of DIOPSIS cameras in insect monitoring, contributing to valuable insight to the broader scientific community. However, data analyses have not been done yet as DIOPSIS cameras have never been compared to other passive sampling techniques before. Unfortunately, the data necessary for the case study was not received, preventing the presentation of any results in this regard. However, a start has been made by the previously mentioned recommendations on how to compare insect monitoring techniques regarding species composition, insect abundance and biomass along with its hypothesis outlined below.

It is hypothesized that DIOPSIS camera data will have a more varied insect species composition, compared to Malaise and pitfall traps. This arose by the fact that Malaise traps mostly capture Hymenoptera species (Matthews & Matthews 1970; Darling & Packer 1988; Noyes 1989) and pitfall traps mostly capture ground-dwelling insects (Skvarla et al. 2014). I also expect a difference in insect species captured by DIOPSIS cameras compared to Malaise traps as a yellow screen is used with DIOPSIS which can attract specific insect species (Noyes 1989). The data gathered by Malaise traps often results in unidentified samples or partial identifications, whereas DIOPSIS cameras automatically identify insects, as long as it was able to identify the insect. Finally, it is expected that biomass cannot be compared across the insect monitoring techniques as the captured species already differed.

4. Conclusion

The decline in insect populations due to anthropogenic influences raises the growing need for effective insect monitoring. However, existing comparisons of insect monitoring techniques often focus on general aspects, such as trap functionality, trap variations, labour, and cost-effectiveness. This lacks insight into why these techniques should be employed. To address this gap, I conducted a comprehensive examination of various insect monitoring techniques, highlighting their advantages, disadvantages, and the challenges associated with meaningful comparisons.

There are many insect monitoring techniques, ranging from passive collection methods like Malaise, Möricke and pitfall traps to active methods like light trapping, netting and image-based insect identification, that offers a spectrum of approaches for researchers. Each technique has its strength and limitations and thus needs to be critically evaluated how variation in trap design or methodology causes the effect of trapped insects. By understanding these effects, data can be combined to give insight into global insect trends.

Furthermore, I provided recommendations to improve future comparative studies, making insect monitoring techniques more transparent, justifiable, and effective in understanding variations in insect abundance, species composition, and biomass across techniques. This is important to transparently justify method choices, addressing biases and to ensure the relevance of monitoring data over time for insect dynamics. In this way a combination of monitoring techniques can enhance data by facilitating large-scale, long-term insect monitoring.

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5. Rebuttal

I would like to thank E. Jongejans for the time in supervising me in the process of writing this essay and the provided feedback on my draft versions that helped me with improving my writing. I would also like to thank him by inviting me to a meeting about the performance of DIOPSIS cameras. It gave me more understanding about the advantages and disadvantages of DIOPSIS cameras and coming along with other people in biology-field.

As feedback was provided, I would like to respond on it.

E. Jongejans, Comment 1: Abstract: I understand why, but this still reads like a proposal, saying what will be done, while the abstract at this point should be about results. So change later.

Response to comment 1: Thanks for the response. Indeed, it did not show any results of the case study but showed more a methodology what was done. That is why I changed it to a result sentence.

E. Jongejans, Comment 2: Abstract: The conclusion part in the abstract could be more concrete. Perhaps give an example or specify the number of studies that made quantitative comparisons as well as the number of studies found to make qualitative comparisons.

Response to comment 2: I implemented this feedback because, even though it is only one sentence extra, it gives an opening / introduction to the table that I implemented later on.

E. Jongejans, Comment 3: Unclarity / formulation of sentences

Response to comment 3: I understand that a lot of sentences were not clear, and that interpretation can be sometimes difficult for the reader. I tried to make it more clear on the ones that feedback was given on, but also on the rest of this essay. I did this by rephrasing the sentences or giving explanations to make it clearer. For instance, "its", "research", "have been proposed" have more context now.

E. Jongejans, Comment 4: Structure of paragraph

Response to comment 4: I also understand this feedback point. In the introduction of each section, my intention was to provide clearer explanations of what readers can expect from the coming paragraphs.

E. Jongejans, Comment 5: Section 2.2: What is your main goal in this section? Quantitative comparisons between different trap types (e.g. Malaise vs pitfall), or comparisons between different flavours of the same trap type (as in Uhler et al. 2022)? At the start of this section you should tell readers what to expect. My worry is that this section turns into a description of general traps types, rather than focussing on quantitative comparisons.

Response to comment 5: The introduction of this section was a big vague which has led to this feedback point. That is why I rephrased and explained better to make it clearer and to understand the goal of section 2.2.