Journaal van Syrphidae

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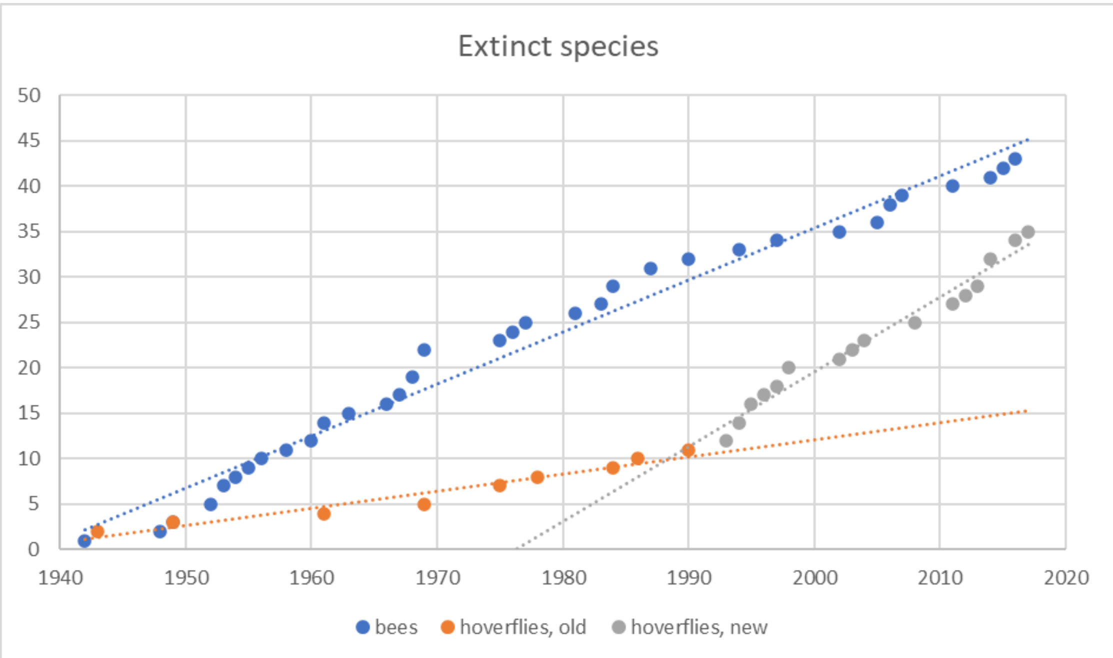

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Drastic acceleration of the extinction rate of hoverflies (Diptera: Syrphidae) in the Netherlands in recent decades, contrary to wild bees (Hymenoptera: Anthophila)

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Abstract. The averaged yearly rate of extinction of hoverfly species (Diptera: Syrphidae) in the Netherlands is shown to be variable over time: over the period 1993–2017, it is nearly five times higher than over the period 1942–1992. There is a sharp demarcation between the two rates at 1992–1993. This sudden change in extinction rates is due to an accelerated extinction rate of species with zoophagous and phytophagous larvae. In species with aquatic saprophagous larvae or saproxylic larvae no rate change is observed. In contrast to hoverflies, extinction rates for bees in the Netherlands are found to be constant over time, higher than hoverflies in the first period, but lower than hoverflies in the last period. Current extinction speeds are 1.0 species a year for hoverflies (= 0.3 % of all species present per year) and 0.4 species a year for bees (= 0.12 % of all species present per year). These results differ in a major way from previous results. Consequently, from the point of view of conservation, hoverflies deserve a more prominent role in conservation policy making.

Keywords. bees, decline, flower flies, insects, pollinators, regional extinction, The Netherlands

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Introduction

The publication by Hallmann *et al*. (2017) on the decline of flying insects caught in Malaise traps in Germany led to a large number of publications on the decline of insect numbers (Wagner 2020). For instance, Hallmann *et al*. (2020) studied the numbers of flying insects attracted to light and the numbers of carabid beetles (Coleoptera, Carabidae) in pitfall traps, yielding evidence for strong declines in numbers for families studied. The presence of a strong decline of terrestrial insects over the last decades is now generally accepted (Kunin 2019, van Klink *et al*. 2020, Wagner *et al*. 2021, van Klink *et al*. 2023).

As for trends in hoverflies, Biesmeijer *et al*. (2006) found the number of species of hoverflies with an increasing distribution trend to be much higher than the number of species with a decreasing trend, both in the Netherlands and in the United Kingdom. These results are based on a comparison of presence or absence in 10 x 10 km squares before and after 1980. For bees, the results were opposite: more declining than increasing species. The idea that hoverflies perform well relatively to bees, at least in western Europe, has been argued by Carvalheiro *et al*. (2013) and Doyle *et al*. (2020). Recent publications, however, have questioned this statement. Hallmann *et al*. (2021) found a decrease of the number of individuals of hoverflies of 89 % and a decrease in species richness of 23 % over a 26-year period (1989-2014) for a river valley in Germany. Barendregt *et al*. (2022) reported similar results, a decrease of 80 % of the number of individuals of hoverflies over 40 years (1982 – 2021) and 44 % of the species over 43 years (1979–2021) for hoverflies in a forest in the Netherlands. Gatter *et al*. (2020) report for migratory hoverflies a decline of individuals of 90–97 % over 40–50 years (based on transect counts 1970–2019 resp. Malaise traps 1980 - 2019). Finally, comparing the period 2008-2022 with 1900–1969, Reemer *et al*. (2024) found as many species of hoverflies with a declining trend (147) as with an increasing trend (146).

These studies combined suggest a strong decline of both the number and the species richness of hoverflies since 1980 in western Europe. Regional extinction is the most drastic form of decline. Since regionally extinct species must also have been in decline, regional extinction is a more conservative variable than decline. Also, primary goal in policy making is most often to avoid regional extinction of species as much as possible. The advantage of studying regional extinction compared to decline is that the former can be studied more easily. Here, we study the national extinction rate for hoverflies in the Netherlands and compare this with the Dutch extinction rate for wild bees.

Material and Methods

Throughout this article, we will compare the number of hoverfly species extinct from the Netherlands with those for wild bees. With extinction speed, we mean the average number of species per year becoming extinct over a particular period. Since the number of species of hoverflies in the Netherlands is slightly lower than that number for wild bees, the extinction speeds cannot be compared directly. Therefore, we also introduce the extinction rate as the extinction speed relative to the number of species (either hoverflies or bees) recorded in the period of time under consideration.

Our analysis is based on the databases of Dutch records of hoverflies and wild bees as present at European Invertebrate Survey–the Netherlands (EIS). These databases include most of the specimens present in Dutch public collections of natural history musea as well as in private collections. Also, records submitted to EIS by experienced observers (bee and hoverfly specialists) are present as well as all records from Waarneming.nl (Waarneming.nl *et al*. 2024) validated by experts. In total, 347 species of hoverflies and 372 species of bees are recorded for the Netherlands. We consider 315 species of hoverflies and 339 species of bees to be or have been indigenous, based on the following criteria: either present both before and after 1900 or presumed present and reproducing since 1900 over a period of at least ten years (Reemer 2018). Details of this assessment can be found in Reemer (2018) for bees and in Reemer *et al*. (2024) for hoverflies. For all these indigenous species, we establish the year of last recording over the period 1942–2022 (provided at species level in supplement 1, sheet 1). Species are considered extinct if they have not been recorded over the last five years 2018–2022. We choose this definition to be as contemporary as possible. The results for other definitions, like ten years, follow straightforward from the ones presented here. If the reader would prefer a definition of 'not seen over the last x years (x > 5)', simply cut-off the results presented at the year 2022–x. For the period before 1942, only very few species became extinct (one species of hoverfly, two species of bees).

We also investigate whether different larval strategies yield different extinction rates. All bee larvae feed on pollen collected by adults or, in case of cleptoparasitic species (cuckoos), by their hosts. Hoverfly larvae lack parental care. Within hoverflies, there is a huge variety in larval biology. Four main groups can be recognized (Rotheray 1993): species with aquatic (or semi-aquatic) saprophagous larvae (n = 60), phytophagous larvae (mycophagous included) (n = 57), saproxylic larvae living (saprophagous associated with wood (Speight 1989)) (n = 49) and zoophagous larvae (mostly aphidophagous) (n = 142). A few species do not fit in any of the four groups, which need not to be considered here, because none got extinct. For only one extinct species (*Psarus abdominalis* (Fabricius, 1794)) the larval biology remains unknown. For bees, the main groups are species nesting in the ground, nesting in wood and their cuckoos (Scheuchl & Willner 2016).

Averaged extinction speed over a period of years is simply calculated as the number of species getting extinct in this period divided by the number of years. Dotted regression lines in graphs are only present to guide the eye. Since the cumulative numbers are not statistically independent, this regression is not used in the calculation. Averaged extinction rates are, by definition, simply the averaged speeds divided by the total number of species present in this period. For these proportions, Wilson's 95 % confidence intervals are calculated and given between [ ].

Results

The cumulative number of extinct species over the years 1942–2017 is reported for both bees and hoverflies (Fig. 1). Note that the total number of species of bees found in this period is 24 (= 7%) larger than the number of hoverflies. Simple visual inspection of the graph suggests that extinction speed for hoverflies is not constant over the years, but accelerates around 1992-1993. Indeed, there is a clear difference between the two periods 1942–1992 and 1993–2017, with extinction speeds of 0.22 [0.12, 0.38] species / year up till 1992 versus 0.96 [0.65, 1.40] species / year afterwards (Fig. 2). The difference is statistically very significant with a p-value of $< 10^{-5}$, Chi2. The extinction speed for hoverflies since 1993 was 4.5 times [2.2, 8.8] higher than before. For bees, the extinction speed is rather constant over the years: 0.63 [0.45, 0.86] species per year for the older years (1942–1992) versus 0.44 [0.25, 0.77] species / year for the more recent years (1993–2017). The difference is not significant (Chi2). Therefore, we conclude that the extinction speed for hoverflies is accelerating since 1993, whereas for bees, it is constant over the years.

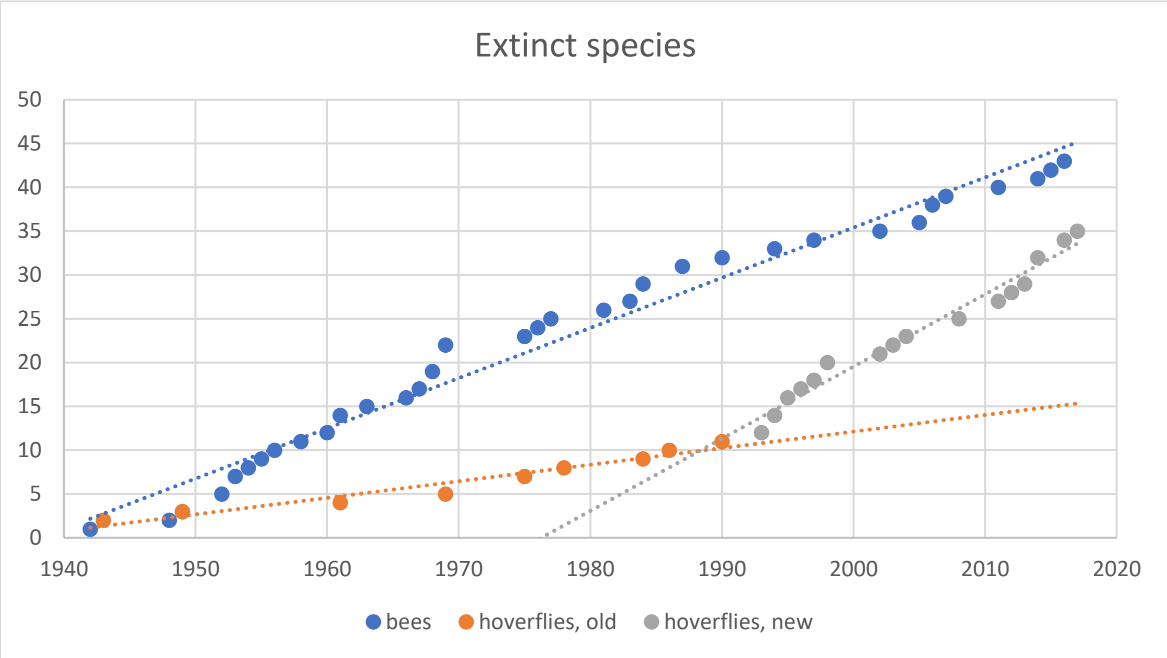

Figure 1. Cumulative number of extinct species over the years for bees (blue), hoverflies up till 1992 (orange) and hoverflies since 1993 (grey). Any extinct species is represented only once, leading to years without dots in the graph. X-axis: year. Y-axis: number. Total number of species considered is 339 for bees and 315 for hoverflies.

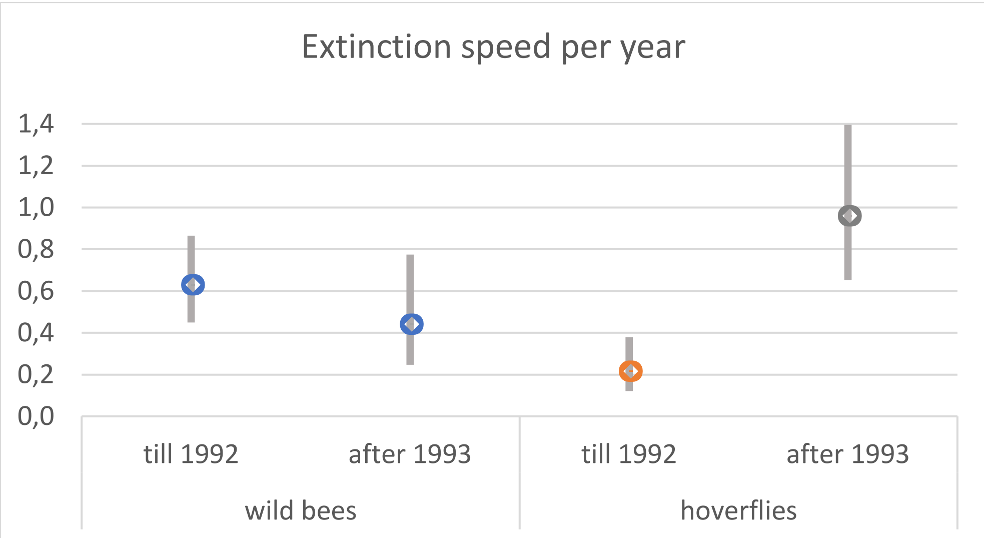

Figure 2. Extinction speeds (average number of extinct species per year), for bees (blue) and hoverflies for the two periods considered (orange and grey), with 95 % confidence intervals.

To investigate differences in patterns of extinction rates over the years between hoverflies and bees, we need to correct for the higher number of species of bees. To achieve this, we present the cumulative experimental distribution function for extinct species, leading to a total value of 1 in 2017 for both groups (Fig. 3). The curves are different (Kolmogorov-Smirnov, $p < 0.01$), as already strongly suggested by the graph. We conclude that the pattern of extinction over the years for hoverflies is statistically different this pattern for bees. More particular: extinction rates for hoverflies are lower than for bees in the period up till 1992 and higher since 1993.

The statistical analysis above is made on the assumption that the observation activity is constant over time. This is obviously not true. A drop in the observation intensity might lead to an artificial raise of recorded extinctions. When we look at the number of hoverfly records (made by experts) per year (Fig. 4), a drop of the number of records just after the abrupt change of extinction speed around 1992-1993 can be observed. However, this drop in total number of records is relatively small and it occurred over a very short period of two years, after which, the number of yearly records reaches an all-time high in 2001. Therefore, the change in extinction speed cannot be explained by the varying number of yearly observations. We checked for both periods 1942–1992 and 1993–2017 whether a correlation between the number of records per year and the number of extinct species per year exist and we found none.

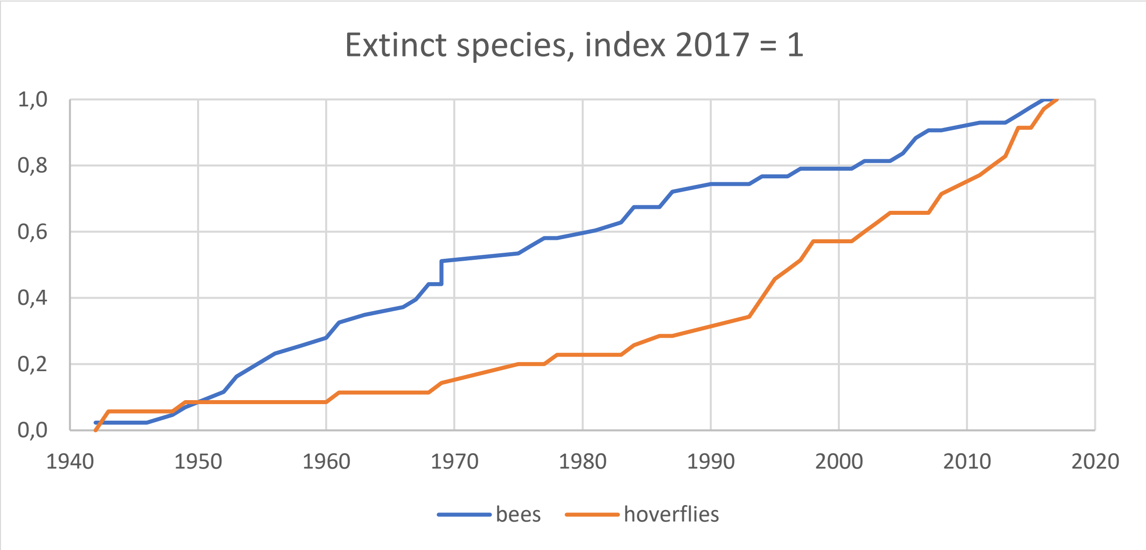

Figure 3. Cumulative empirical distribution functions of extinct species over the years for bees (blue) and hoverflies (orange). Index 2017 = 1. X-axis: year. Y-axis: fraction (cumulative).

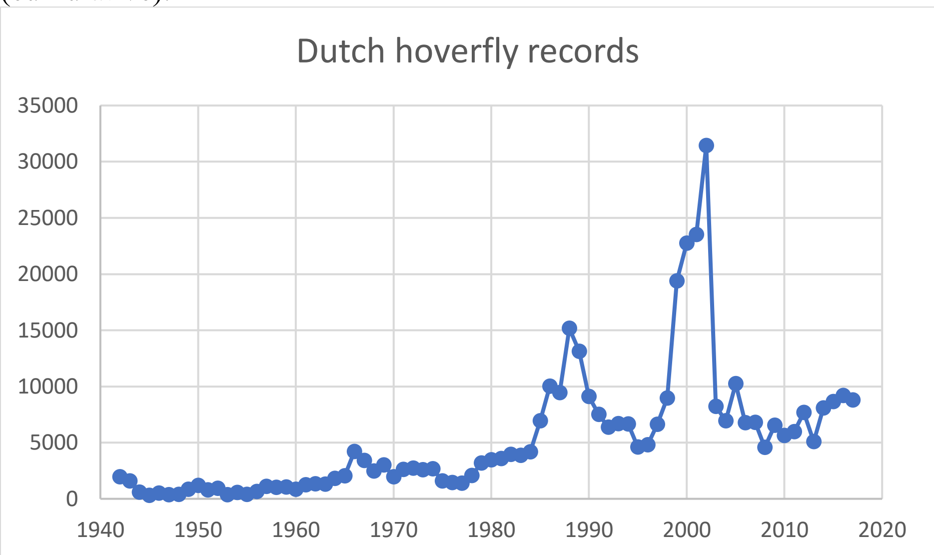

Figure 4. Number of Dutch records for hoverflies. X-axis: year. Y-axis: number of records. Two or more records from the same species and same sex from the same day, location and observer are disregarded. More details in Barendregt *et al.* (2009).

The cumulative relative fraction of extinct species differs significantly between the four main groups of hoverflies based on larval biology (Fig. 5). The extinction rate is more or less constant for species with aquatic larvae and saproxylic larvae. For species with phytophagous and with zoophagous larvae it is lower in the first period (up till 1992), accelerating rapidly from 1993 onwards.

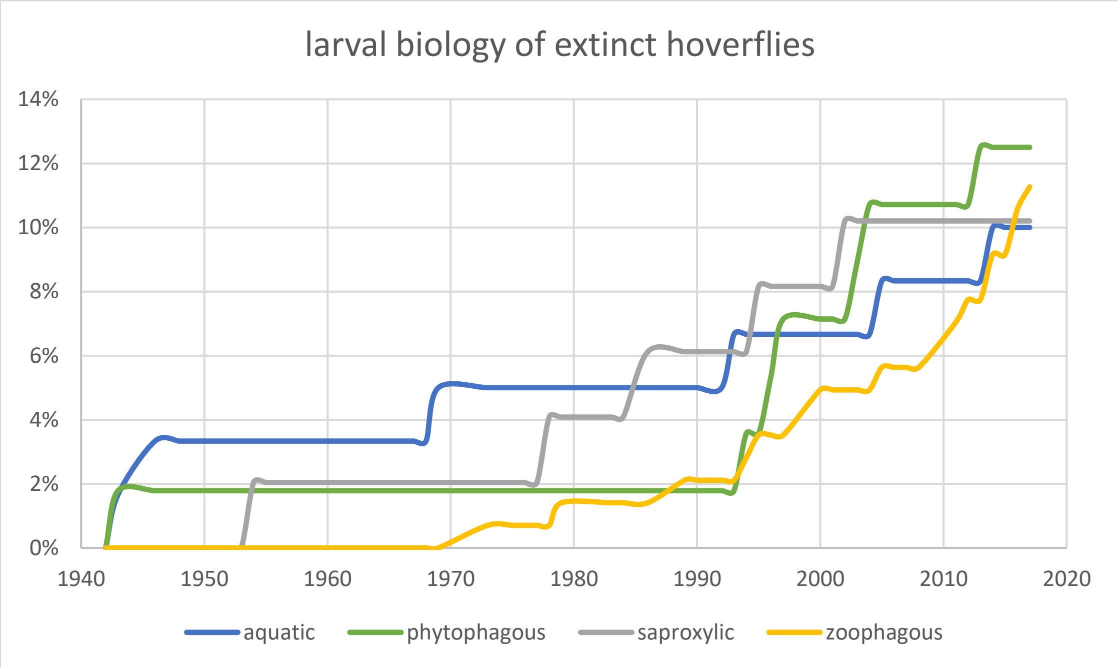

Figure 5. Cumulative relative percentage of extinct species over the years for hoverflies for the four major groups of larval biology, relative to the total number of species with that biology found: aquatic (blue; n=60), phytophagous (green; n=56), saproxylic (grey; n=49) and zoophagous (yellow; n=142). X-axis: year. Y-axis: percentage.

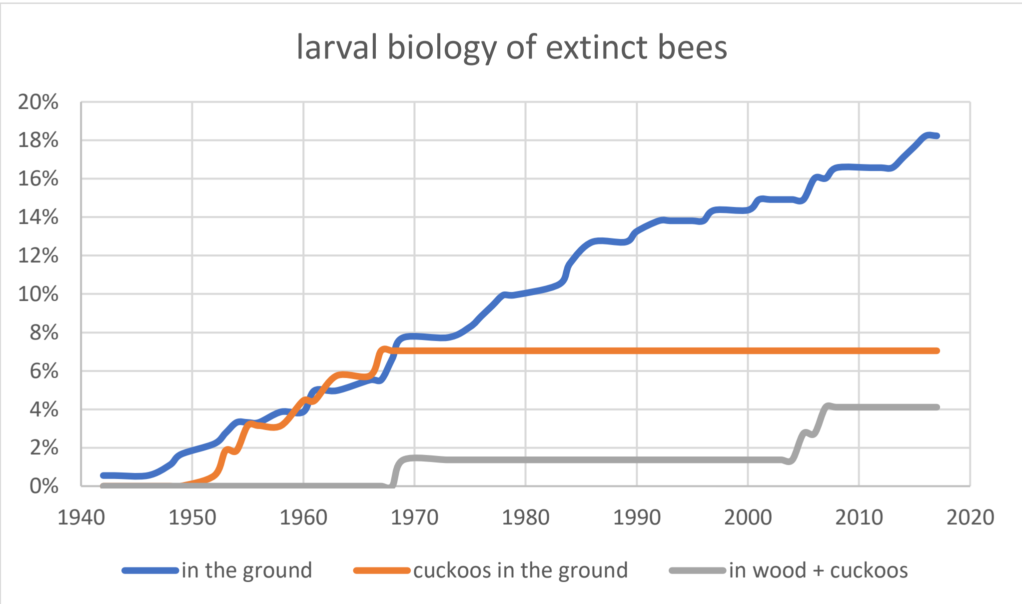

Figure 6. Cumulative relative percentage of extinct species over the years for bees for the three major groups of larval biology, relative to the total number of species with that biology found: nest in the ground (blue; n=181), cuckoos in nests in the ground (orange; n=77) and nests in wood including their cuckoos (yellow; n=73). X-axis: year. Y-axis: percentage.

Discussion

The current (1993–2017) extinction rate for hoverflies is estimated to be nearly five times higher than the historical rate (1942–1992) and also more than twice as high as the current extinction rate for bees. At first glance, this might be a surprise, since the biology of adult bees and hoverflies is similar, both groups generally feed on flowers. However, the adult stage of these insects comprises only a minor period of their lifecycle. The larval biology of hoverflies differs hugely from that of bees and is also much more diverse. Generally speaking, the highest current extinction rates are found in species with exposed larvae (zoophagous hoverflies), the lowest in species with sheltered larvae (saproxylic, see also Reemer (2005) and bees nesting in wood, Fig. 6), though the phytophagous hoverfly species do not agree with this pattern. Of course, pesticides might reach the phytophagous larvae via the plant, although we are not aware of studies demonstrating this. The rapid decline of species with zoophagous larvae is consistent with the findings of Gatter *et al.* (2020) and Barendregt *et al.* (2022). Based on this observation, one might wonder whether airborne stressors might be part of the explanation for the high increase in the extinction rate occurring in the early nineties of the last century (Brühl *et al.* 2021, Ryalls *et al.* 2022). It is well established that nitrogen deposition peaked in the Netherlands in the late eighties (Bobbink 2021). For another stressor, the usage and toxicity of pesticides, historical data do not go that far back, but clearly the usage of pesticides in the Netherlands was much higher some 20–30 years ago than the current level (Staal *et al.* 2014) That said, the effects of pesticides should be measured not only by their volume, but also by their toxicity. For instance, the until recently widely used neonicotinoid imidacloprid is estimated to be 7000 times more toxic for honeybees than the previously used DDT (Pisa *et al.* 2015). The hypotheses of airborne stressors contributing to extinction of hoverflies can only be tested experimentally in controlled environments. Such a study is currently being done at Stichting Bargerveen / Radboud University. Calvo-Agudo *et al*. (2019) have shown that neonicotinoids in honeydew can lead to mortality amongst hoverflies. This fact is not only relevant for species whose adults feed on honeydew, like *Xylota* Meigen, 1822 species, but possibly also for species with zoophagous larvae. Mantingh & Buijs (2020) have shown that insecticides, neonicotinoids included, occur in problematic concentrations in Dutch nature reserves. Another stressor, possibly relevant for all larval biologies, is climate change and associated drought (Zeegers & van Steenis 2009, Morris & Ball 2021). Since hoverflies are better represented in moderate climates and bees more so in warmer climates (Reverté *et al.* 2023), climate change can be expected to affect hoverflies more negatively than bees.

Species have not only disappeared, but new ones have arrived in the Netherlands as well. Over the period 1993–2017, 11 species of hoverflies and 11 species of bees have appeared (details at species level in supplement 1, sheet 2), corresponding to introduction speeds of 0,44 species a year for both hoverflies and bees. For hoverflies, this number is much lower (less than half) than the extinction speed, hence, the total number of species of hoverflies is decreasing. For bees, it is about equal. About seven species of the newly found species of hoverflies have likely arrived from central or even southern Europe, supposedly associated with climate change, and 1-3 species have likely been accidentally introduced by man (forestry). Most of the new arrivals among bees are southern species. Over the years 2018–2023 (not in this study), the number of new southern bees in the Netherlands is increasing even more rapidly (database EIS). Hence, the total number of bees present in the Netherlands is currently increasing.

In conclusion, the extinction rate for hoverflies in the Netherlands is accelerating, whereas for bees it is not. The steep decline of hoverflies is supported by other recent studies, both for number of species (Hallmann *et al.* 2021, Barendregt *et al.* 2022) as for abundance

(Gatter *et al.* 2020, Hallmann *et al.* 2021, Barendregt *et al.* 2022), all local studies. On a national scale, our results agree with Biesmeijer *et al.* (2006), who reported a mild increase for hoverflies comparing periods before and after 1980. However, for the present time, Reemer *et al.* (2024) found the number of species of increasing and decreasing hoverflies for The Netherlands to be equal. Our results contradict the general conclusions of Carvalheiro *et al.* (2013), claiming that extensive species loss occurred before 1990 and agree with Van Dooren (2016), claiming that slowing down of decline of species richness can only be proven for bees, not hoverflies.

The Dutch Government aims to have strongly improved the position of pollinators by 2030 (Nationale Bijenstrategie 2023). Our results make it clear this will be a Herculean task. It calls for rapid major measures and policies for the protection of hoverflies, especially by reducing the impact of stressors like nitrogen, insecticides, climate change, drought and intensive agriculture, since current policies have proven to be insufficient and ineffective (Outhwaite *et al.* 2022, Vujić *et al.* 2022, Engelhardt *et al.* 2023, Ecologische Autoriteit 2024).

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