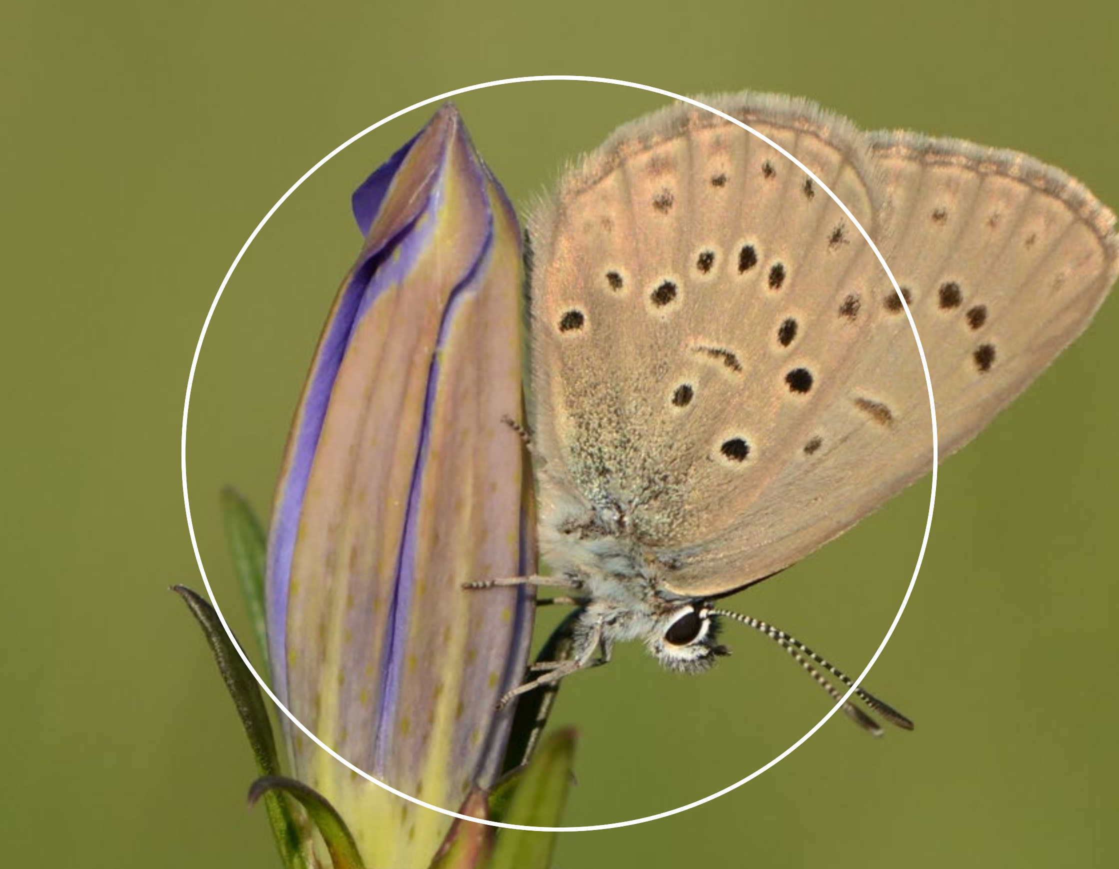

Living with Biodiversity: the butterfly dimension

Prof.dr Michiel F. Wallis de Vries

Farewell address upon retiring as Special Professor of Insect Ecology and Conservation at Wageningen University & Research on 24 March 2022

WAGENINGEN UNIVERSITY & RESEARCH

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Dear Rector, Ladies and Gentlemen,

There is no doubt about it: we are living in a time of crises. In plural, first because we are facing multiple humanitarian crises across the globe, and second because it is becoming increasingly clear that the 'we' concerns not only humans, but also our interacting with the biological diversity around us, which could well lead to the 6th mass extinction event in Earth's history. As humans, we need to re-invent our ecological niche on this planet. Living with biodiversity definitely is one of our main challenges for the coming century. It requires a combination of, on the one hand, science to develop understanding about problems and solutions, and care and engagement on the other hand, to successfully implement these solutions in practice.

This certainly applies to 'the little things that run the world', as the late icon of conservation biology Edward Wilson called them: insects. In studying insects, with butterflies as perhaps the best investigated insect group, we can take the bumpy and winding road of learning by doing to improve our living with biodiversity. Currently, we hear a growing public outcry to revive the human dimension in organising society. In this farewell lecture, I want to explore with you the butterfly dimension in co-existing with biodiversity.

The joy of exploring

To illustrate the joy and inspiration found in discovering, observing, and recording butterflies, let me quote to you from the notes of a 19th Century explorer of the Malayan Archipelago: "During my very first walk into the forest of Batchian, I had seen sitting on a leaf out of reach, an immense butterfly. ... I could not catch it as it flew away high up into the forest, but I at once saw that it was a female of a new species of *Ornithoptera* or 'bird-winged butterfly', the pride of the Eastern tropics. ... During the succeeding months I only saw it once again. ... I had begun to despair of ever getting a specimen, as it seemed so rare and wild, till one day, ... I found a beautiful shrub ... and saw one of these noble insects hovering over it. ... I found it to be as I had expected, a perfectly new and most magnificent species, and one of the most gorgeously coloured butterflies in the world. ... The beauty and brilliancy of this insect are indescribable, and none but a naturalist can understand the intense excitement when at length I captured it. On taking it out of my net and opening the glorious wings, my heart began to beat violently, and the blood raised to my head, and I felt much more like fainting than I have done when in apprehension of immediate death. I had a headache for the rest of the day, so great was the excitement produced by what will appear to most people as a very inadequate cause."

The explorer in question was Alfred Russel Wallace, self-made naturalist from a family of modest means. He was fascinated by insects and aspired to become a scientist but also needed to make a living, which he successfully did by setting up expeditions to bring back specimens for museum and private collections, amounting to 110,000 insect specimens alone. But he brought back much more than collection material: descriptions of new species, data on their distribution – and, most importantly, scientific insights, resulting in ground-breaking papers on the biogeography of species (including the famous 'Wallace line' dividing the Oriental and Australian faunal regions) and evolution by natural selection. His ideas on evolution grew in 1858 and the manuscript that he sent to Charles Darwin, much admired by Wallace, forced Darwin to finally publish his long-delayed On the Origin of Species in 1859, the same year as the butterfly discovery described above. Wallace also popularised his discoveries in the widely acclaimed travel account *The Malay Archipelago* (1869), from which my quote derives.

Knowing about insect diversity

Wallace's example as an eminent student of biodiversity still stands today. It highlights several aspects of the butterfly dimension I want to present: caring, observing, describing, and recording as the basis for the scientific study of biodiversity. It is interesting that Wallace already focussed on insects, especially butterflies, moths, and beetles, because our perspective on biodiversity is still heavily biased towards vertebrates. As humans we have a significant share in the biomass of mammals on Earth and together with our livestock, we dwarf the share of wild mammals (Bar-On et al., 2018). Yet, when we include the biomass of terrestrial arthropods, largely insects, then it is revealed that these outweigh all these vertebrates (even when including birds). This is even more apparent at the species level, where 59% of all described species on Earth concern insects, noting that probably 80% of insect species still remains to be discovered.

Even in our own backyard, insect diversity can be astonishing. Biologist Luc Hoogenstein took advantage of his long-COVID affliction to record all species living in his garden and so far found an amazing 1468 species, two thirds of them insects, including more than 400 species of moths and butterflies (Waarneming.nl/bioblitz).

The large share of insects in terms of species and biomass translates into an important role of insects in ecosystem functioning and services to human society, such as pollination, pest control, maintenance of soil fertility, and even supply of protein. It is all the more important, then, to have reliable information on how insects are doing. Unfortunately, this information is scarce. Global assessments of trends in biodiversity are primarily based on vertebrate species. The 2020 global Living Planet Index (LPI) shows an alarming 68% decline in vertebrate populations between 1970 and 2016 (WWF, 2020). What would be a comparable figure for insects? The answer is that we don't know. Data on a global scale simply show such huge gaps that only explorative estimates can be made. One of the few long time series, analysed by Caspar Hallmann and colleagues (Hallmann *et al.*, 2017), made headlines in the media across the world. It reported a 75% loss of biomass in flying insects in Germany over a 25-year period. What, then, is the situation at home in the Netherlands, was asked by our members of parliament. Again, an enormous knowledge gap was revealed.

Insect declines

What can we actually say about trends and declines in insect diversity? Which factors are driving them? And what can we do to bend the curve towards recovery, as required by the biodiversity strategy of the EU? In the next part of my lecture, I would like to present some knowledge that we have gained and lessons that we have learned over the past 10 years. Of course, I will draw mainly from the studies carried out in collaboration with many others during the years of my Special Chair in Insect Ecology and Conservation at Wageningen University.

First, we will look at trends. Here, we are fortunate that we can benefit from a wealth of evidence on especially butterflies. Starting in the 19th Century, this charismatic group of insects has drawn a great number of amateurs to start collections, often joined by professionals from museums and research institutes. Together, this early effort of citizen science provides information on the distribution of species, but not on their abundance. Butterfly counting only started in the 1970s and in the UK, Ernie Pollard and colleagues established simple, but systematic protocols that led to the start of the first Butterfly Monitoring Scheme in 1976. In the Netherlands, Dutch Butterfly Conservation (De

Vlinderstichting) was established in 1983 and launched its own national monitoring scheme in 1990. With an ever expanding network of butterfly volunteers, and in collaboration with Statistics Netherlands (CBS), we are now able to produce reliable trends in butterfly abundance, not only at a national level, but also at regional and even local levels.

These data do confirm an alarming decline. Butterfly abundance in the Netherlands has halved in less than three decades. We do not have sufficient data on butterfly abundance from before 1990. But we have been able to determine the trend in distribution over the preceding century. This reveals that between 1890 and 1990, there was an overall decline in butterfly distribution of 67% (Figure 1). Together, the decline by two thirds before 1990 and the halving in abundance since then, amount to a massive loss of between 80 and 90% of butterflies (Van Strien et al., 2019). And this should probably be regarded as a conservative estimate.

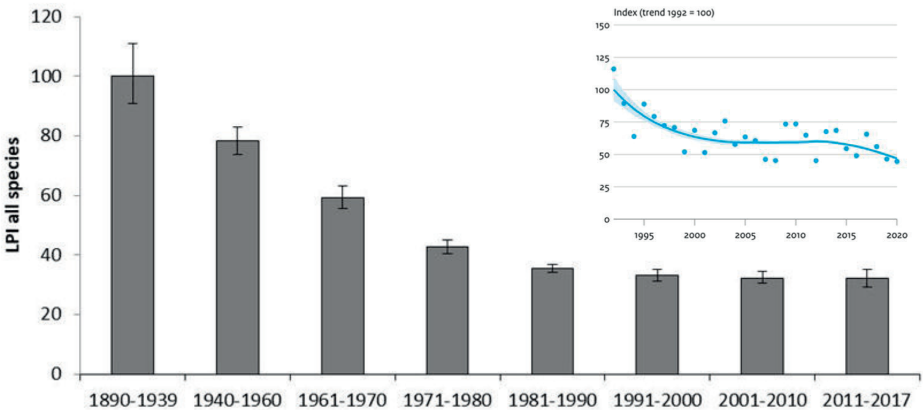

Figure 1: Multi-Species Indicator (±95% confidence intervals) for butterfly species of the Netherlands (n=71 species), showing distribution trends per species derived from List Length analysis using presence/absence data from 5 km×5 km sites. The inset shows the abundance trend of butterfly species between 1992 and 2020.

Not all species have suffered equally. The status and trends can be explained by the underlying traits of individual species. Currently common butterfly species tend to disperse well and have a high reproductive output. Also, these typically are associated with warmer and drier regions. Common as well as increasing in abundance, are species with a high growth rate that are able to produce several generations in a single year, thanks to an early emergence in spring (WallisDeVries, 2014). Unfortunately, these

so-called winners comprise only a minority of the entire species community.
We thus see a changing species community unfold over a period of decades. Remaining populations of vulnerable species may, in fact, give a misleading picture of the state of biodiversity with ongoing habitat loss. In many cases they can be identified as 'living dead': their occurrence reflects a landscape of low use intensity that has disappeared and they may go extinct at any moment. For a time, then, species richness is higher than expected on the basis of current habitat availability (Figure 1). A so-called extinction debt remains to be paid (see Figure 3).

Habitat loss and extinction debts

In the late 1980s, we were not yet aware of this process. On hindsight, I can say that, in 1989, I encountered my first living dead, a population of Alcon Blue (*Phengaris alcon*) near the river Overijsselse Vecht. This butterfly shows many characteristics of a declining species: it is a poor flier, reproduces slowly, and depends on a symbiosis with gentians and ants in low-productive wetlands. These areas of wet heathlands and hay meadows were widespread in the early part of the 20th Century, but they had largely gone when I came along. The population formed part of a small cluster, each limited to a few individuals only and separated from each other by kilometres of monotonous conifer woodland. Fifteen years later, all four subpopulations had gone.

This gradual process of extinction can be clearly illustrated by the fate of the Grayling butterfly (*Hipparchia semele*), a characteristic species of another low-productive environment, dry heathlands and coastal dunes. Our analysis of its distribution shows a period of fluctuating occupancy between 1950 and 1990, followed by steady and sharp decline (Van Strien *et al*., 2011). However, closer inspection of the underlying dynamics of colonisation and extinction at the level of kilometre squares, reveals that colonisation probabilities have been decreasing since the 1960s already, whereas the chance for a site to remain occupied remained high and even showed a tendency to increase until 1990. The net result of the lower rates of colonisation without a further increase in persistence, was that sites that went extinct were not re-colonised anymore. Without a cohesion at landscape scale, this led to a halving of the distribution of the Grayling and an alarming 90% decline in its population size. At the other end of the world, the same fate likely awaits the few island populations of Wallace's Golden birdwing butterfly, which is now considered Near Threatened due to habitat loss, although actual population trends remain unknown.

You will appreciate that we have covered some ground in our exploration of the butterfly dimension. Professional and amateur naturalists have been motivated to go out and describe species, record their distribution and systematically monitor their populations. As a result, we can assess patterns in species richness and changes in species communities and population trends of individual species.

Climate change and habitat fragmentation

We will now move on to try and understand the causes behind these changes. Recently, scientists have coined the Anthropocene as the name of our current era, where humans have become a driver of geological processes, especially by massively increasing and accelerating the flows of carbon (by mining and mobilising fossil fuels), nitrogen (by producing reactive nitrogen from chemical fertilisers, traffic and industry) and phosphorus (again by mining). Our ecological footprint dominates the planet, with 58% of the land's surface under intense human pressure (WWF, 2020). We are becoming increasingly aware that we are in the process of overshooting boundaries for planetary stability. Scientists have estimated that we are moving beyond a safe operating space for humanity with respect to land use, biochemical flows, climate change and biosphere integrity (Steffen *et al.*, 2015). Here, the human dimension meets the butterfly dimension.

Let's see what butterflies and other insects tell us about environmental change. With regard to climate, we have observed in the temperate zone, where the pace of change is most rapid, that insects such as butterflies and dragonflies are significantly expanding their ranges polewards (Mason *et al.*, 2015). However, they are lagging behind the speed of climate change. From the entire species community, only the good dispersers are able to shift their range fast enough. The poor dispersers will need to adapt or face the risk of extinction. For butterflies, we were able to assess a temperature index of local species communities, based on the relative abundances of species from cooler or warmer climatic ranges. Using the monitoring schemes in different countries, we could then compare the warming of the species community with the actual climatic warming (DeVictor *et al.*, 2012). Over a period of 18 years, the lines of equal temperature moved northwards by 249 km – a staggering 13 km each year – in contrast to the butterfly community, which shifted only by 114 km, i.e. less than half of the climatic warming. For dragonflies, we do have a similar monitoring scheme in the Netherlands, but at a European scale this remains to be developed. Instead, we used distribution data over a period of 25 years to assess such changes in the dragonfly community. This revealed a similar time lag as for butterflies, probably resulting from a combination of dragonflies being the better dispersers, but with longer generation times slowing down local population turnover (Termaat et al., 2019).

For butterflies, we have recently examined the impact of one of the major obstacles for successful range shifts: habitat fragmentation. To do so, we used long-term monitoring data from the Netherlands and Finland to determine how species communities change in relation to the availability of habitat in the landscape. The study demonstrated that both the area of semi-natural habitats (those that are only little impacted by human activity), as well as their spatial distribution, influenced the rate of species turnover (Fourcade *et al.*, 2021). The consequences of these two aspects of habitat fragmentation differ between the 98 species considered. The colonisation of warm-adapted and mobile species was favoured when semi-natural habitats were spatially dispersed, offering stepping stones for dispersal. In contrast, this raised the extinction risk of less mobile cold-adapted species, even more so when habitat area was low. This group of species depends on large habitat clusters for their persistence. These findings emphasise the importance of nature conservation at landscape scale to mitigate the impact of climate change on biodiversity.

The Alcon Blue is one of these vulnerable, poorly dispersive species, not because it is specifically cold-adapted, but because its host plant, the Marsh gentian (*Gentiana pneumonanthe*), and probably its preferred host ant Myrmica ruginodis as well, depend on wet conditions under the influence of local groundwater, including systems with a perched water table. From a recent landscape ecological analysis, we could identify the important hydrological gradients that are key for the butterfly. The disappearance of several populations could be linked to the combination of current climatic extremes and the decade-long desiccation of the landscape by surrounding land use. On drier sites this led to extinctions in drought years. On other sites, this led to an ecological trap for the butterfly, whose wet heathland habitat got restricted to the wettest depressions in the landscape. These depressions risk to be flooded during climatic extremes of heavy summer precipitation. In 2016 this led to the extinction of the Alcon Blue in multiple sites (Wallis DeVries *et al.*, 2021). So, here a long process of drying up of the landscape ended in the drowning of the butterfly. Conservation at landscape scale is therefore not only required in order to maintain viable populations of this species, but also to preserve the hydrological systems on which its habitat depends.

Nitrogen deposition

After carbon, nitrogen is the other main element that has become increasingly available in the Anthropocene. Never before in the existence of planet Earth was the availability of reactive nitrogen (in reduced or oxidised form) so high as nowadays. Through atmospheric deposition, nitrogen levels also have raised significantly in nature reserves, even though the sources may be far away. Nitrogen availability has been a limiting nutrient in most ecosystems. Most species, therefore, are adapted to cope with low nitrogen levels. Few species have specifically adapted to the formerly rare places in the landscape – such as riverine areas and coastal meadows or temporarily disturbed sites – where nitrogen accumulates. It is not surprising then, that a majority of species is declining and only the minority of species from productive environments are benefitting. This is known for plants, but we have also demonstrated this to be true for butterflies. We can illustrate it with our nitrogen indicator, that, analogous to the above-mentioned temperature index, reflects the relative abundance of species from nitrogen-rich to nitrogen-poor environments (Wallis DeVries & Van Swaay, 2017). Applied to data from our monitoring scheme, we see a continuing increase over the last 30 years (Figure 2), which indicates that the majority of species from nitrogen-poor environments are still losing ground. Indeed, the 2020 Living Planet Report from the Netherlands (Wereld Natuur Fonds, 2020) showed a stronger decline of both insect and vertebrate animal species on heathlands at the highest level of nitrogen deposition, although the substantial decline at the lower level indicates that critical loads are also exceeded there. This underlines the need for effectively reducing nitrogen emissions in the coming years.

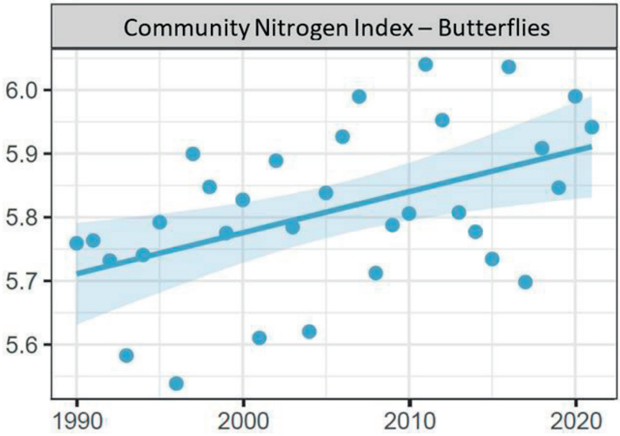

Figure 2: Trend of the Community Nitrogen Index for butterflies in the Netherlands between 1990 and 2021. The increase indicates a shift in abundance towards a greater share of nitrogen-tolerant species at the expense of nitrogen-sensitive species.

Pesticides

A further influence of land use on insect diversity concerns the application of pesticides to protect crops and control outbreaks of insects, ticks and mites. In recent decades, the detrimental impacts of neurotoxic pesticides such as neonicotinoids and fipronil have raised great concern. However, their impact on non-target insects is difficult to assess in the field. This is not only due to the difficulty of disentangling all the possible drivers of population dynamics, but also because of the occurrence of sublethal effects. In the breeding facilities for cabbage whites (*Pieris brassicae*) at both the lab of Entomology and Dutch Butterfly Conservation, we experienced these first hand in 2010. The caterpillars grew fine and pupated successfully to butterflies, but that was the end of the line: the butterflies were extremely inactive and reproduction failed almost completely. We groped in the dark on the possible causes and only after, an extensive search a likely candidate was found: the Brussels sprouts that served as host plants had been grown from seeds coated in fipronil against cabbage root fly (*Delia radicum*). This circumstantial evidence led to further study to validate these observations (Gols et al., 2021). In a first experiment, we compared the growth, survival, and egg production of cabbage whites on plants grown from fipronil-coated seeds against an untreated control. We again observed a successful caterpillar development, pupation, and butterfly emergence, but egg production was reduced by 55% on the fipronil-treated plants, with a substantial proportion of unviable eggs, lowering reproductive success even further. A second experiment was conducted to establish a dose-effect response. Again, this only became apparent at the reproductive stage, with reduced butterfly survival and impaired egg production. Thus, the negative impact of fipronil on this non-target insect, even at very low concentrations, was serious, but was only revealed with much delay, after the larvae that had eaten the contaminated plants pupated into butterflies. Sublethal effects on larval activity of damselflies have also been found for the neonicotinoid thiacloprid (Barmentlo et al., 2019). Despite a moratorium on the use of fipronil and a number of neonicotinoids in many applications since 2013, they are still allowed in others, including flea collars and ant killers around the house. Concentrations in surface water often still exceed health standards (Bestrijdingsmiddelenatlas.nl). This seems to have even increased for fipronil, where it is also clear that detectability itself is a concern, let alone that cumulative impacts of combinations of different products may be expected. These findings stress the necessity to adopt stricter test protocols for the authorisation of pesticides, explicitly taking sublethal effects into account.

Light pollution

I want to shed some light on one more concern of human impact on biodiversity that has emerged during the last decade: light pollution. More and more studies, from Wageningen and elsewhere, show that this negatively affects night life, including moths, a very species-rich group that plays an important role in the food chain (as herbivores and as food for birds and bats) and probably in pollination as well. Moths are not only attracted to artificial light sources, the light, especially the shorter waves, also disrupts their feeding and impacts on pheromone production and reproductive behaviour. Our field data on population trends have confirmed that night-active moths that are attracted by light show significant declines, in contrast to species that are day-active species or not attracted by light (Van Langevelde et al., 2018). Data from a recent field experiment with manipulated light availability confirm the negative effects of artificial lighting (Van Grunsven *et al.*, 2020). Light pollution thus may have a greater role in insect declines than previously suspected.

Working towards recovery

I have reviewed important emerging insights on the formidable threats that the Anthropocene poses for the preservation of insect diversity. How should we halt the decline and work towards recovery? Prof. Jeff Harvey from NIOO rallied a large number of insect ecologists across the globe and together we compiled a comprehensive set of recommendations for actions that are needed in science, in practice, public outreach, and in policy (Harvey *et al.*, 2020). The final words were clear on the sense of urgency: "We must act now!" Of course, 'now' is the only option to act anyway. So, let's cover the key actions.

As a scientist, I should stress that there are always knowledge gaps that need to be filled. For example, we are only starting to grasp the mechanisms of how nitrogen deposition impacts on food quality for herbivorous insects and which species are especially affected (Nijssen *et al.*, 2017; Vogels *et al.*, 2020). Excess nitrogen may lead to nutritional deficiencies of phosphorus, but also of micro-nutrients. Alternatively, increased nitrogen-based plant defences may render plants inedible. Depending on which mechanisms are operating, different restoration measures are required.

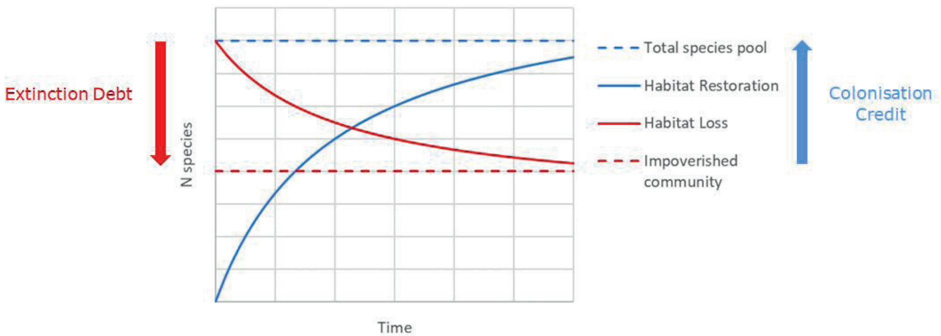

Figure 3: Schematic representation of the time lags in species extinction after habitat loss and in species colonisations after habitat restoration. These lead to the build-up of extinction debts and colonisation credits, respectively. Restoration ecology aims to turn the tide from paying extinction debts to cashing colonisation credits.

Local habitat management

Let's start at a local spatial scale with an example of grazing practice on heathlands. In the province of Noord-Brabant, we investigated the abundance of insects across a range of heathland types: from wet to dry and from ungrazed to heavily grazed. When plotting the weighted abundances of the various species of butterflies, day-active moths, grasshoppers, and ants along the axes of moisture and grazing intensity, we see that there is a large scatter in the optimal occurrence between species (Wallis DeVries *et al.*, 2016). This emphasises that a one-size-fits-all type of management will fail to preserve insect diversity in these heathlands. Instead, it is crucial to manage for heterogeneity and to cherish both the biotic gradient of grazing intensity as well as the abiotic gradient of moisture. This also serves to mitigate the impact of climatic extremes at local level.

Upon closer inspection of this scatter of species over environmental space, a pattern was apparent, with a cluster of pioneer species associated with higher grazing intensity on dry heathland and another species cluster of older heathland stages associated with low grazing intensity in wet heathland. In a follow-up experiment, we tested if managers can steer the composition of insect communities by manipulating grazing intensity. Grazing was excluded on overgrazed sites, whereas on grass-encroached heathland it was intensified by rotational sheep grazing. Over a six-year period, the impacts were compared with a control under a regular grazing regime.

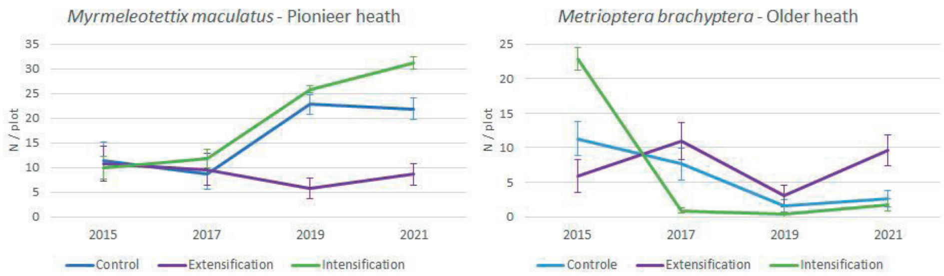

Figure 4: Contrasting trends in the abundance between two grasshopper species with different habitat preference under grazing regimes of intensification and extensification, compared with a control under regular grazing on dry heathland (Wallis de Vries et al, in prep.).

The grasshoppers shown in Figure 4 by example, indeed showed the expected contrasting responses of species associated with either pioneer or older heathland stages. The former benefitted from the intensification by rotational grazing. The latter declined under intensification. That they did not clearly benefit from extensification was probably due to

the extreme drought in three consecutive summers.
This experiment exemplifies the process of learning-by-doing in a combination of field experiments closely followed up by monitoring and data analysis. It also offers a basis to define indicator groups that can be used to assess the impact of management on habitat heterogeneity.

Restoration at landscape scale: changing the narrative

Managing local conditions to improve habitat quality for insects is one thing, indeed an essential one, but conservation at landscape scale is quite another matter. Here, we face three important challenges: 1) maintaining or restoring habitat conditions at the scale of ecosystems, 2) overcoming habitat fragmentation, and 3) improving baseline quality in areas outside nature reserves. The first challenge is considered by many as the focal task of nature conservation. However, restoration at landscape scale often extends beyond the boundaries of nature reserves.

Here, insect diversity meets land use. Species ecology and conservation practice meet society with its many stakeholders and interests, with a heavy emphasis on economic profitability. If, as humans, we are to succeed in our mission to bend the curve of biodiversity loss towards recovery, we need a different narrative in dealing with our environment. Terry Pratchett, the famous creator of the 41-volume fantasy multiverse of Disc World, also co-authored four books on the Science of Discworld, in which he reflects on the reality and the magic of humanity. He renamed our species as Pan narrans, the story-telling chimpanzee, in order to stress two key elements: our close evolutionary relation with other apes and the role of stories in explaining why it is that humans and not chimpanzees dominate the world. The power of narratives in shaping our ecological niche has not only been convincingly outlined by Terry Pratchett. More recently, in his bestseller Sapiens, the historian Yuval Noah Harari has elaborated on the idea, and demonstrated how the concept of money has grown to a key myth on our road towards the Anthropocene. In the context of land use, it has allowed strategies of maximising agricultural productivity to flourish, but led to high demands for energy and nutrient resources, expanding monocultures and increasing livestock densities, as well as excessive nutrient and pesticide loads and disrupted hydrological systems to sustain this productivity. The downside of this strategy for maximisation instead of optimisation, is an alarming biodiversity loss and an undermining of ecosystem services, increasing the vulnerability to disturbances, such as disease outbreaks and climatic extremes. The result is a landscape where even formerly common species, such as the Wall brown butterfly (*Lasiommata megera*) have disappeared. Do we want to live in such a world?

In the present crisis of the Ukranian conflict, the agribusiness lobby is already calling out to downsize the European Farm to Fork strategy towards a more sustainable agriculture. It is a token of saddening cynicism to exploit one crisis to mask another. And this will certainly not solve the nitrogen crises and the land use crisis that our impoverished butterfly communities have made so abundantly clear. Fortunately, more and more people realise that we urgently need to change our narrative, not only to preserve biodiversity, but also to redefine the role of humanity in its interaction with the living world, with biogeochemical cycles and environmental conditions.

Learning from the butterfly dimension

I propose that we use the butterfly dimension (Figure 5) to get to grips with our own human dimension. Everything starts with caring, Biophilia, as Edward Wilson called it. In Wallace's pioneering work, this translated to describing new species, recording their distribution and developing theories about their biogeography and evolution. In more recent times, we have developed protocols for counting butterflies in order to monitor their populations. Indeed these are also starting to be applied to the world of Wallace's birdwing butterfly (Mas'ud *et al*., 2020)! And we see that this acquired knowledge generates a positive feedback on the motivation to keep getting engaged for biodiversity. With monitoring and ecological research, we are improving our understanding on habitat conditions at local and landscape scales. This paves the road for the development and testing of effective measures for conservation and restoration. The monitoring allows us to identify indicators for our biodiversity performance and evaluate whether they are indeed effective. If not, we should adapt them and try again: in a complex world, it is not a shame to fail, that is what learning by doing is about.

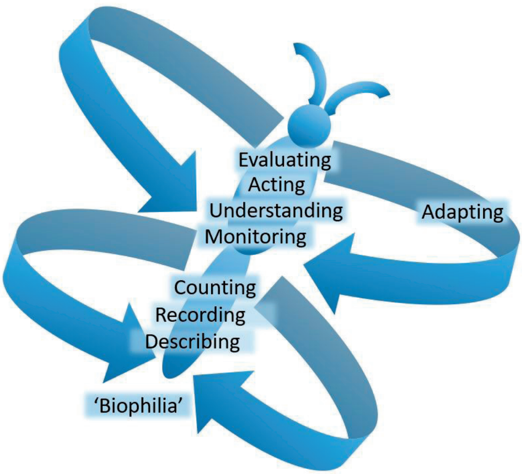

Figure 5: The Butterfly Dimension builds from the caring 'biophilia' to actions of describing, recording and counting species, which generates a positive feedback on further engagement. The acquired knowledge can grow to a next stage of monitoring, understanding through research, taking action for conservation and evaluating the impacts, which feeds back into adaptive management.

In the Netherlands of the early 20th Century, Jac. P. Thijsse was a great catalyst in opening our eyes to the narrative of biological diversity in cultural and semi-natural landscapes. In present times, traditional land use practices offered a fruitful source of inspiration to Jap Smits and Jinze Noordijk, both entomologists, in restoring biodiversity of a semi-natural heathland landscape (Smits & Noordijk, 2013). The concept of rewilding has a similar ultimate aim of preserving biodiversity, but from the perspective of enhancing natural processes with minimal human interference. Together with ARK Natuurontwikkeling, we are currently exploring the potential of trophic rewilding with large herbivore grazers to restore butterfly diversity in the project 'Wild about butterflies' (Vlinderstichting.nl/wild-van-vlinders). There is even potential to cash conservation credits by applying modern no-nonsense restoration practices, such as topsoil removal on former agricultural land (Wallis DeVries & Ens, 2010; Wallis de Vries & Bult, 2020). Biodiversity may benefit from all of these approaches. But whatever perspective we take in habitat restoration, the successes are not only about optimising local conditions and management, but largely about overcoming limitations at landscape scale, allowing species to disperse and restoring suitable conditions for their populations to thrive.

More than 75% of people in the EU completely agree that we are responsible for preserving our natural environment, and in the Netherlands this is even almost 90% (Sanders et al., 2020). Biodiversity and environmental sustainability feature high on the national and European agendas. And in the Netherlands we have a new ministry of Economic Affairs and Climate and a special minister for Nitrogen and Nature. There is a new nature-inclusive ambition that is heart-warming. But can we make it work in practice?

Key messages to bend the curve

Let me supplement this narrative with key messages from the butterfly dimension.

At a global, but certainly a European scale, biodiversity declines stress the need to reform our land use practices on the basis of closed nutrient cycles, with carbon and nitrogen as the primary targets, but this approach should extend to the use of other resources, such as water and other elements. The challenge here is to come up with economic incentives that facilitate this reform. The central principle is not rocket science: reward sustainability and charge open-ended use of resources. This includes, of course, payment for damage to ecosystem services and biodiversity. There is no doubt that implementation is and will be unruly, but there is no question about the urgency anymore.

At the national and landscape scale in the Netherlands, the present nature policy has a disproportionate focus on Natura 2000 areas alone, which is not in line with Europe's biodiversity strategy. This focus should be broadened and scaled up. Natura 2000 areas can be considered to hold the pearls of biodiversity. However, these pearls will be lost one by one if we fail to connect them. In the Netherlands this requires urgently completing the national nature network (NNN). In turn, this necessitates adapting land use in the surrounding landscape to allow this network to function. This thought is at the heart of the Deltaplan for Biodiversity Recovery (Samenvoorbiodiversiteit.nl), a plan grown out of the collective action of the full diversity of stakeholders, from farmers to scientists and from banks to environmental NGOs. The link to biodiversity can be strengthened here by the emerging concept of 'Basiskwaliteit Natuur': a baseline quality for nature is a welcome newcomer in the policy world in order to support biodiversity (Biesmeijer *et al.*, 2021).

However, there is a huge challenge in translating nature policy to a practice of learning-by-doing. This applies to both nature reserves and agricultural areas. Policy has relied too much on the assumption that policy instruments will reach their target, because that is what they were designed for. Progress is then measured by monitoring the efforts, but without the crucial link to their actual performance. This is now changing. Key performance indicators (KPIs) are increasingly used to get a better view on the outcomes. Examples from the dairy sector (Biodiversiteitsmonitor.nl) are the areas of permanent grassland, herb-rich grassland and landscape elements, as well as emissions of nitrogen and carbon per hectare, However, the message from the butterfly dimension is that such indicators should always be linked to indicators of actual biodiversity. The practice of monitoring the effectiveness of nitrogen policy has also shown that it is necessary to keep including actual measurements of nitrogen deposition to calibrate the AERIUS deposition model. It would be a great step forward if this approach could also be integrated in the use of KPIs for monitoring the effectiveness of nature-inclusive farming.

In nature reserves, biodiversity data do play a greater role in evaluating policy and management. But here, actual monitoring of biodiversity in the SNL subsidy system requires a stronger scientific basis, as current protocols for especially insects and plants typically lack the standardisation to allow reliable assessments of even basic trends in distribution, let alone population trends. Another weakness is that the monitoring of habitat management and restoration has been poorly documented in space and time. Therefore, from both sides, the existing information does not allow the development of a learning-by-doing practice, as the butterfly dimension demands. Fortunately, the new Implementation Programme for Nature from the Ministry of Agriculture, Nature and Food Quality does take monitoring more seriously and is elaborating a scheme that will allow to link conservation practice to biodiversity trends and to scale up from the local to a national level. I hope that this will be instrumental in finally bending the curve towards biodiversity recovery!

Concluding remarks

Rector, ladies and gentlemen, I am coming to the conclusion of this farewell address. For the past 10 years, I have been given the opportunity to set up and shape this Special Chair in Insect Ecology and Conservation. I am extremely grateful to Dutch Butterfly Conservation (De Vlinderstichting) and Wageningen University for making this possible! The underlying ambition of De Vlinderstichting was to re-establish the link between its work on citizen science and conservation of butterflies, moths, and dragonflies on the one side and academic research and education on the other. De Vlinderstichting was founded almost 40 years ago at Wageningen University, so it is of great value to see the link with its native environment restored! For the first five years, my chair was hosted at the Lab of Entomology, where insect biology is at the heart of all activities. For the second period of five years, I returned to my own roots of scientific education, at the Chair Group of Plant Ecology and Nature Conservation, where I could benefit from the orientation on conservation biology and link the ecology of butterflies to other pollinators and the quality of their host plants. I want to thank both Chair holders Marcel Dicke and David Kleijn for their generous hospitality and my gratitude includes the staff, the bachelor, master, and PhD students as well as postdocs, also from other universities, that made it possible to collaborate on science for impact. I want to thank you all for your lively and stimulating company on this journey! A journey that I will now continue at De Vlinderstichting and in which I will fortunately keep traveling along with many of you in the coming years.

Furthermore, I would like to extend my thanks to the many volunteers that recorded and counted butterflies, moths, and dragonflies over all these years. It is thanks to their efforts that we have been able to arrive at scientifically robust assessments of their state and trends!

I would like to end with a more personal word of thanks to friends and family. I have enjoyed many long-lasting friendships and close family bonds. Even if we don't see each other as often as I would like to, your value in supporting and enriching my life and work is immense. Finally, words cannot express the bliss of sharing this journey with the love of my life José and my children Steven and Renske. I'm afraid that, over the years, I brought you rather close to the butterfly dimension, but I hope that it will inspire you and motivate you in finding and shaping your respective ecological niches in life! And this goes for you all!

Ik heb gezegd!

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Living with biodiversity definitely is one of the main challenges for humanity in the coming century. In studying insects, with butterflies as one of the best investigated insect groups, we can learn what it takes to meet this challenge. In my farewell address, I outline the 'butterfly dimension' of getting engaged for biodiversity through a process of basic describing, recording and counting, which leads on to evidence-based learning-by-doing: combining monitoring, research and adaptive management.

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