The SEEA-EEA experimental biodiversity account for the Netherlands

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Bogaart, P., E. Polman, R. Verweij and C. van Swaay, 2020, The SEEA-EEA Experimental biodiversity account for the Netherlands. Statistics Netherlands and Wageningen University, The Hague, Wageningen, The Netherlands. 56pp.

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Executive Summary

This report presents the first Biodiversity Account for the Netherlands, which is a thematic account in the international SEEA-EEA (System of Environmental-Economic Accounts – Experimental Ecosystem Accounts) framework. It's main use within this framework is to monitor the intrinsic, ecological, quality of the ecosystems providing ecosystem services to society.

The Account collects indicators on two hierarchical levels: ecosystems and species. In many cases these levels are tightly coupled, since many ecosystem indicators are constructed from species abundance and/or distribution information. The third, genetic, level of biodiversity, is not taken into account here, due to a general lack of data on this topic.

Trends in biodiversity are reported on two time scales: a longer time scale, mostly 1990 onwards, and a shorter 'accounting' period, 2006–2013, which is also the focus of the other current SEEA-EEA accounts for the Netherlands (extent; condition; physical and monetary supply/use of ecosystems).

In the first sections of the Account, a number of established indicators for ecosystem extent and species abundance are collected and integrated and formatted as SEEA-EEA consistent accounting tables. Of these, the Red List and Living Planet Index are the most relevant.

The overall Red List Indicators, measuring the threat level of species, remained fairly stable since 1995, both in terms of the number of threatened species (Red List 'length'), as in summed threat level (Red List 'color'). However, there are some marked differences between ecosystems and between species groups. Red List length and color for terrestrial ecosystems worsened by ≈20% since 1995, while these indicators for freshwater and wetland ecosystems improved by ≈10–15% until 2016, after which a slight deterioration started. Red List Indicators for Mammals and Dragonflies improved since 1995, but for Birds, Reptiles, Amphibians and Butterflies the indicators worsened.

A similar picture emerges when considering the Living Planet Index (LPI), which measures the abundance of selected species groups. Overall, the LPI for the Netherlands increased slightly during the whole data period of 1990–2016, and remained stable during the accounting period 2006–2013. Zooming in on individual species groups and ecosystem types reveals marked differences. LPI for wetland birds, dragonflies, mammals and reptiles increased (improved), while LPI for farmland birds and butterflies decreased (worsened). When looking at broad ecosystem types, LPI for wetlands increased (improved), while LPI for almost all other ecosystem types (agricultural, coastal dunes, heathland and urban) decreased (worsened). For Forest the LPI remained stable.

A major 'ecological' conclusion from this first part of the Account, and the underlying primary reports (WWF Nederland, 2015; van Strien et al., 2016), is that since 1990, biodiversity in the Netherlands, although slightly improving overall, has been declining for many dry and open natural ecosystem types and associated species groups, although the variability is large, and biodiversity in some ecosystems and species groups have experienced improvements, especially wetlands and dragonflies. A first 'technical' conclusion therefore is that, given the strong underlying and systematic variability, aggregated indicators are often not a good representation of biodiversity changes. A second technical conclusion is that interannual variation calls for sophisticated time-series analysis techniques to derive useful statistics for shorter, 'accounting' time scales.

A second section introduces experimental results on trends in spatial patterns of butterfly species diversity. Comparison with spatial explicit indicators of landscape composition reveals that locations of minimum diversity of farmland butterflies correspond with regions of large-scale and monotonous agriculture, highlighting the links between regional-scale landscape and land-use management and local-scale biodiversity. It is expected that the methods developed in this section can be successfully applied to other countries and regions where adequate monitoring data are available.

Acknowledgements

We gratefully acknowledge the financial support of the Ministry of Agriculture, Nature and Food Quality, as well as the Ministry of Infrastructure and Water Management and the Ministry of Economic Affairs and Climate of the Netherlands that have made the research for this publication possible. In particular, we would like to thank Joop van Bodegraven for coordinating this effort on behalf of the ministries.

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1 Introduction

Biodiversity is the variety of life on Earth. It includes all organisms, species, and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems (UNEP, 2010). Biodiversity typically measures variation at the genetic, the species and the ecosystem level. Here, genetic diversity refers to the diversity in all the different genes contained in all the living species. Species diversity refers to the diversity in all the different species and within species. Ecosystem diversity refers to the variation in all the different habitats, biological communities and ecological processes, as well as variation within individual ecosystems.

Biodiversity accounts are part of an ecosystem monitoring framework developed under auspices of the United Nations (System of Environmental-Economic Accounting – Experimental Ecosystem Accounting (SEEA-EEA) (UN et al., 2014; UN (2017). The SEEA-EEA prescribes the development of a series of core accounts, reflecting the extent and condition of ecosystems and the supply and use of ecosystem services (physical and monetary). In addition, a number of thematic accounts can be complied, including land, water, carbon and biodiversity accounts. SEEA-EEA defines biodiversity as "*the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems*" (Convention on Biological Diversity, article 2, entitled "Use of Terms"). The relationship between ecosystem services and biodiversity is complex. Biodiversity is a fundamental characteristic of ecosystems, underlying ecosystem service supply. In addition, changes in biodiversity frequently result in changes in ecosystem extent and condition. In the SEEA-EEA, biodiversity is considered a characteristic of ecosystems rather than an ecosystem service.

Selecting suitable indicators for biodiversity accounting is challenging. The Conference of the Parties to the Convention on Biological Diversity agreed on a list of indicators for assessing progress towards the 2010 biodiversity target at the global level. The four indicators concerning the state of biodiversity are: 1) trends in extent of selected ecosystems, 2) trends in abundance and distribution of selected species, 3) trend in status of threatened species and 4) changes in genetic diversity. These indicators are comparable with indicators mentioned in the SEEA-EEA technical guidance document on experimental biodiversity accounting (UNEP-WCMC, 2015, figure 1.3), which focusses on 3 tiers (Figure 1). The **first tier** captures information on the ecosystem characteristics used to define different classes of Ecosystem Units (or important areas of biodiversity habitat) and their extent. The **second tier** captures information on species richness, extinction risk and potentially other characteristics for ecosystem and other accounting reporting units. The **third tier** captures information on (genetic) species abundance within an ecosystem and other accounting reporting units. Therefore, indicators corresponding to these topics are selected for the biodiversity account, based on relevance (for policy) and data availability.

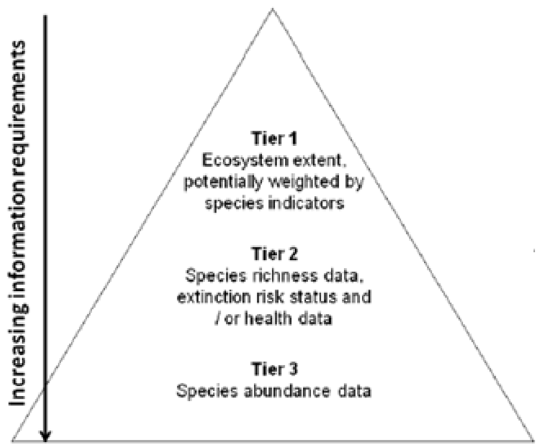

Figure 1. Tiered approach to biodiversity accounting.

In the Netherlands, flora and fauna species are monitored by many volunteers and professionals, organized in NGO's such as Sovon (Dutch Centre for Field Ornithology), De Vlinderstichting (Dutch Butterfly Conservation), RAVON (reptiles, amphibians and freshwater fish); EIS (insects); FLORON (plants); ANEMOON (marine); The data obtained by these organizations are crucial for research and policy issues.

One important measuring network is the Network Ecological Monitoring (NEM)[1]. This network is a partnership consisting of ministries, provinces, Statistics Netherlands and Netherlands Environmental Assessment Agency (PBL). The NEM coordinates data collection by the NGO's and processes these data to derive several forms of official statistics, which are disseminated through the Environmental Data Compendium (CLO)[2].

In addition to the NEM, several websites exist where flora and fauna observations are gathered, such as waarneming.nl and telmee.nl. Validated observations are collected in the Dutch National Database Flora and Fauna (NDFF)[3].

In 2016 Statistics Netherlands and Wageningen University started a three-year project 'Ecosystem Accounting for the Netherlands', on behalf of the Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment of the Netherlands. The project's aim is to test and implement SEEA EEA ecosystem accounting for the Netherlands. The choice was made to develop the core accounts and include carbon and biodiversity as thematic accounts. The focus of the research project is primarily on terrestrial ecosystems (land and inland waters) and not on marine ecosystems (sea and ocean).

The objective of this report is to compile the first biodiversity accounts for the Netherlands using the SEEA EEA framework as guidance. This work is new as worldwide there is still little experience with this new kind of ecosystem accounts. The Dutch Biodiversity Account is mostly based on official biodiversity indicators, published on the CLO. Only the experimental spatial analyses in Section 4 are based on data provided by the Dutch Butterfly Conservation directly to Statistics Netherlands to enable occupancy modelling.

[1] http://www.netwerkecologischemonitoring.nl

[2] https://www.clo.nl/en

[3] https://www.ndff.nl

1.1 Biodiversity – the wider picture

This SEEA-EEA Experimental Biodiversity Accounts is focused on the trends in biodiversity on the national scale, during a fixed accounting period 2006–2013. For a good understanding of the state and trends of biodiversity on this limited scale it's useful to sketch briefly the state and trends in biodiversity as larger and longer scales.

The 2019 IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service) global assessment of biodiversity reports in their Summary for Policymakers that Biodiversity is "declining faster than at any time in human history", and across all levels of biodiversity (ecosystems, species, genes): "75% of the land surface is significantly altered, 66% of the ocean area is experiencing increasing cumulative impacts, and >85%of wetlands (area) has been lost". "The average abundance of native species in most major terrestrial biomes has fallen by at least 20%, mostly since 1900, and an average of around 25% of species in assessed animal and plant groups are threatened". "Globally, many local varieties and breeds of domesticated plants and animals are disappearing", and "biological communities are becoming more similar to each other in both managed and unmanaged systems within and across regions" (Díaz et al., 2019).

According to IPBES, "the direct drivers of change in nature with the largest global impact have been (starting with those with most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species".

A commonly used indicator for biodiversity is the Living Planet Index (LPI), as developed by the World Wildlife Fund (WWF, 2014; 2018). On the global scale, the latest index shows an overall decline of 60% in vertebrate population sizes between 1970 and 2014. Regionally, and for certain habitats, this decline is even more pronounced, e.g. in the tropics, with 89% loss in South and Central America, and an 83% decline since 1970 for freshwater species.

Within the Netherlands, the LPI concept is also used to systematically monitor biodiversity changes across a suite of species groups (including invertebrates) and habitats (See Section 3.2 for more details). Between 1990–2014, the overall state of biodiversity, as indicated by the LPI increased slightly, although significant differences between habitats were observed: LPI for freshwater animals increased considerable, while LPI for farmland and open semi-natural habitats declined. LPI for woodlands remained stable (van Strien et al., 2014)

A topic that drew significant attention recently is the decline of insects and pollinators in special, both globally and in Western Europe. Hallmann et al. (2017) found that in Germany between 1989 and 2016 total flying insect biomass declined 76–82%. This strong decline on was confirmed by e.g. Seibold et al. (2019), who found that between 2008 and 2017 in German grassland sites arthropod biomass, abundance and species richness declined by 67%, 78% and 34%, respectively. Temporal decline was stronger in sites embedded in landscapes with a higher cover of agricultural land. For forest sites, biomass and species richness declined by 41% and 36%, respectively. For the Netherlands, van Strien et al. (2019) combined historical opportunistic butterfly observations with modern monitoring data to conclude that between 1890 and 2017 butterflies declined by 80%.

1.2 Outline

The biodiversity account collects indicators on multiple levels: ecosystems and species. In many cases these levels are tightly coupled, since many ecosystem indicators are constructed from species abundance and/or distribution information. Thus, tiers and 1 and 2 are fully covered (Chapters 2 and 3), and tier 3 partially (Chapter 3), in the sense that abundance data are used as indicators, but are in most cases insufficient to allow for estimation of total population sizes at the national level. The third, genetic, level of biodiversity, is not taken into account here, due to a general lack of data on this topic.

The account is 'experimental' in two ways. First, it contributes towards the SEEA experimental ecosystem accounts (UN et al., 2014). Second, it contains some experimental work on spatial patterns in biodiversity based on occupancy modelling (Chapter 4). As such the biodiversity account contains a mixture of established, 'official' statistics on biodiversity, and novel, experimental work. This report thus is only a first step towards a full biodiversity account. The information provided here is complementary to the information on biodiversity provided in the separate report on Ecosystem Condition for the Netherlands (Lof et al., 2018).

N.B. In many cases indicators from the Environmental Data Compendium (CLO) are used and put into context. To guarantee alignment between this Account and the CLO, general interpretations of trends are copied verbatim from the CLO.

2 Ecosystem diversity

The first level of biodiversity is on the ecosystem level. Ecosystems are ecological entities, and therefore are of interest for their own sake. Ecosystems also provide a habitat for species, and are therefore connected to the species-level of biodiversity.

Two different sources of data on ecosystem diversity have been considered:

1. The Nature and Landscape Index, which is a national inventory of all natural areas for which some ecological policy has been defined
2. The SEEA-EEA ecosystem type map of the Netherlands.

The main difference between these two data sources is that the Index only shows ‘official’ nature (i.e., those areas where nature is the policy objective), while the SEEA-EEA map shows all natural areas. The Index does include different and additional units (i.e. multiple types of semi-natural grassland) and data sources not considered in the SEEA-EEA map, and thus provides additional information. Therefore, results from both data sources are presented.

2.1 The Nature and Landscape Index

The Nature and Landscape Index (Index NL) is a typology of natural areas, describing their nature in terms of management types. These management types can be used to regulate the management of natural areas, and constitute a basis for agreements between the provincial authorities and the area managers about targets and resources. A management type is therefore not a specific form of management, such as integrated forest management, but a type of natural area which requires a particular form of management. Examples of management types include 'dry heathland', 'wet heathland', 'dune woodland' and 'shifting sands'. Index NL is developed to assess the quality of natural areas and landscapes and the way this quality is developing (CLO 1544).

Areas of Index NL management types are available for 2014 (Table 1). From this data it can be seen than the majority of the Netherlands nature is either *sea and intertidal* (N01.01), which is beyond the scope of this current account, *Forest* (N14–17) and *Water* (N02–04). Forest (25% of all nature) is mostly composed of ≈56% production forest and ≈30% semi-natural forest. Grassland (10% of all nature) is mostly composed of herb- and fauna rich semi-natural grassland (52%). Wetlands (4%, excluding open water) are about equally divided between lowland fens and upland ombrotrophic bogs.

Unfortunately, data for other years were not available, so that no changes could be identified.

Table 1. Composition of all nature in the Netherlands, as defined by the Nature and Landscape Index. The Index has a hierarchical structure of which only the first two levels have been translated to English. "Absolute" percentages and red bars indicate the coverage of a unit or group of units, relative to the total area of the Netherlands. "Relative" percentages and blue bars indicate the coverage relative to the total area of the previous level (if less than 100%).

Nature management type Level 1		Area (ha)	Cover (abs)	Level 2	area	abs	rel	Level 3	area	abs	rel
N01	Large-scale dynamic natural	445669	34%	N01 Large-scale dynamic natural	445669	33.6%		N01.01 Zee en wad	406755	30.6%	91.3%
								N01.03 Rivier- en moeraslandschap	21579	1.6%	4.8%
								N01.02 Duin- en kwelderlandschap	12853	1.0%	2.9%
								N01.04 Zand- en kalklandschap	4482	0.3%	1.0%
N14–N17	Woodland	336247	25%	N16 Production forest	191234	14.4%	56.9%	N16.01 Droog bos met productie	166671	12.6%	87.2%
								N16.02 Vochtig bos met productie	24563	1.8%	12.8%
				N15 Dry semi-naturalforest	103678	7.8%	30.8%	N15.02 Dennen-, eiken- en beukenbos	94068	7.1%	90.7%
								N15.01 Duinbos	9609	0.7%	9.3%
				N14 Moist semi-natural forest	34454	2.6%	10.2%	N14.03 Haagbeuken- en essenbos	16976	1.3%	49.3%
								N14.02 Hoog- en laagveenbos	10503	0.8%	30.5%
								N14.01 Rivier- en beekbegeleidend bos	6975	0.5%	20.2%
				N17 Cultural heritage forest	6881	0.5%	2.0%	N17.03 Park- en stinzenbos	4046	0.3%	58.8%
								N17.01 Vochtig hakhout en middenbos	1855	0.1%	27.0%
								N17.02 Droog hakhout	628	0.0%	9.1%
								N17.04 Eendenkooi	352	0.0%	5.1%
N02–N04	Water	296317	22%	N04 Water, not flowing	273474	20.6%	92.3%	N04.04 Afgesloten zeearm	149843	11.3%	54.8%
								N04.02 Zoete plas	114712	8.6%	41.9%
								N04.01 Kranswierwater	7593	0.6%	2.8%
								N04.03 Brak water	1327	0.1%	0.5%
				N02 Rivers	18083	1.4%	6.1%	N02.01 Rivier	18083	1.4%	
				N03 Streams and sources	4759	0.4%	1.6%	N03.01 Beek en bron	4759	0.4%	
N09–N13	(Semi) natural grassland	138570	10%	N12 Pasture and arable	89721	6.8%	64.7%	N12.02 Kruiden- en faunarijk grasland	73095	5.5%	81.5%
								N12.04 Zilt- en overstromingsgrasland	6131	0.5%	6.8%
								N12.05 Kruiden- en faunarijke akker	5059	0.4%	5.6%
								N12.06 Ruigteveld	2437	0.2%	2.7%
								N12.01 Bloemdijk	1676	0.1%	1.9%
								N12.03 Glanshaverhooiland	1323	0.1%	1.5%
				N13 Bird habitat	21167	1.6%	15.3%	N13.01 Vochtig weidevogelgrasland	20286	1.5%	95.8%
								N13.02 Wintergastenweide	881	0.1%	4.2%
				N10 Wet meadows	17128	1.3%	12.4%	N10.02 Vochtig hooiland	13519	1.0%	78.9%
								N10.01 Nat schraalland	3608	0.3%	21.1%
				N09 Salt marshes	6778	0.5%	4.9%	N09.01 Schor of kwelder	6778	0.5%	
				N11 Dry meadows	3776	0.3%	2.7%	N11.01 Droog schraalgrasland	3776	0.3%	
N05–N06	Wetlands	49512	4%	N05 Marshland	26213	2.0%	52.9%	N05.01 Moeras	23160	1.7%	88.4%
								N05.02 Gemaaid rietland	3053	0.2%	11.6%
				N06 Ombothrophic bogs	23299	1.8%	47.1%	N06.04 Vochtige heide	13736	1.0%	59.0%
								N06.03 Hoogveen	3758	0.3%	16.1%
								N06.01 Veenmosrietland en moerasheide	2390	0.2%	10.3%
								N06.06 Zuur ven of hoogveenven	1864	0.1%	8.0%
								N06.05 Zwakgebufferd ven	1197	0.1%	5.1%
								N06.02 Trilveen	354	0.0%	1.5%
N07	Heathland	35517	3%	N07 Dry heathland	35517.18	2.7%		N07.01 Droge heide	32211	2.4%	90.7%
								N07.02 Zandverstuiving	3306	0.2%	9.3%
N08	Coastal Dunes	26042	2%	N08 Coastal dunes (open)	26042	2.0%		N08.02 Open duin	19416	1.5%	74.6%
								N08.01 Strand en embryonaal duin	2857	0.2%	11.0%
								N08.03 Vochtige duinvallei	2283	0.2%	8.8%
								N08.04 Duinheide	1486	0.1%	5.7%

2.2 SEEA-EEA ecosystem type map

For 2006 and 2013 Land Cover and Ecosystem Unit (LCEU) maps for the Netherlands were developed as part of the SEEA-EEA Ecosystem Extent account (van Leeuwen et al, 2017; Remme et al., 2018, p. 77). In the updated SEEA-EEA terminology (UN et al., 2017), these maps largely correspond to Ecosystem Type maps, because most map units correspond to ecosystems. Some exceptions are the built-up areas that are split up by user in economic sectors, and several 'functional' units, such as floodplains (UN et al., 2014; ¶2.81).

Figure 2 shows the LCEU / Ecosystem Type map of the Netherlands, for 2013, while Figure 3 illustrates the breakdown of total area in the various Ecosystem Types, using two hierarchical levels.

Figure 2. Ecosystem Type map of the Netherlands, 2013. Modified from Van Leeuwen et al, (2017)

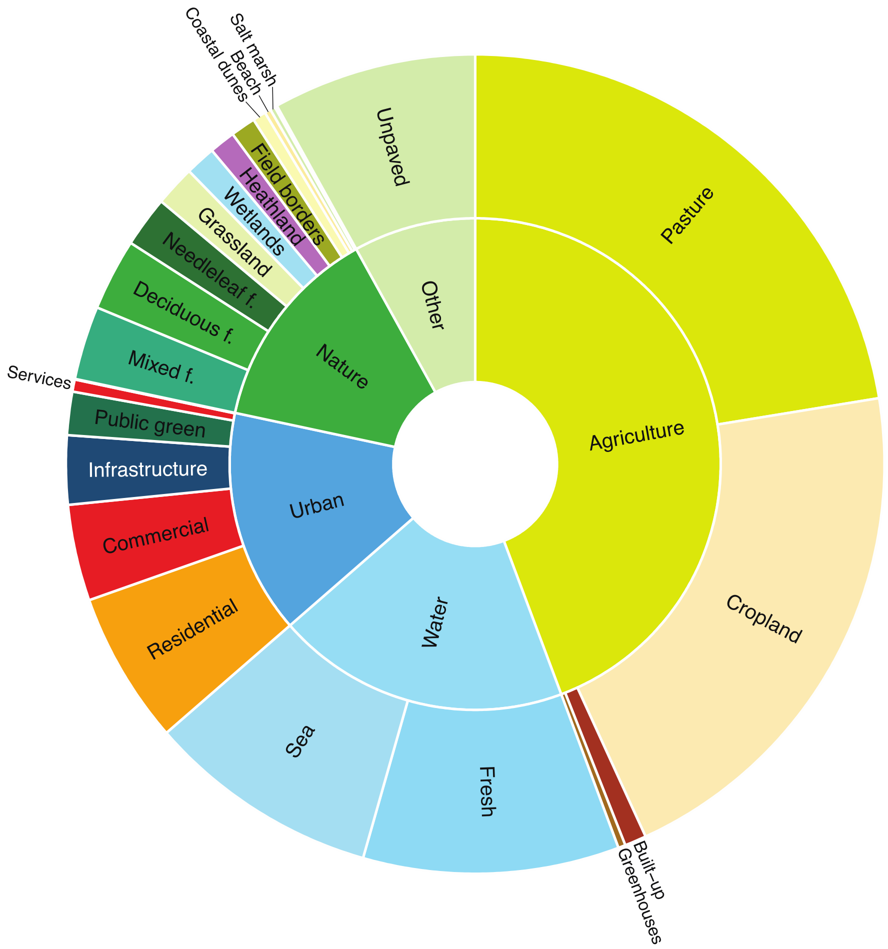

Figure 3. Data visualisation of the Ecosystem extent of the Netherlands (2013), using two hierarchical levels.

2.2.1 Ecosystem extent account

Since the LCEU map is available for both 2006 and 2013, the changes in Ecosystem Type during this accounting period can be analyzed. Table 2 shows the results of this analysis in the form of an Ecosystem Extent account.

Most natural ecosystems have increased in extent during this period, especially *wetlands* (+29%), mostly due to gains from *Agriculture* land. *Coastal dunes*, *salt marshes* and *drift sand* have a decrease in area. Of the anthropogenic ecosystem types, the strongest gains are in the *built-up* area (mainly from *other unpaved*) and ecological *field borders* (mainly from *agricultural* areas). The strongest losses are in *Agriculture* (mainly to *other unpaved*) and *Other unpaved* (mainly to agriculture). This illustrates the multiple types of other unpaved, including temporarily fallow land and land set aside for urban development. It should be noted that a (small) part of the differences in extent between 2006 and 2013 are due to reclassification, see Remme et al. (2018) for details.

Table 2. Ecosystem Account for the Netherlands, 2006–2013. The highest additions and subtractions are indicated in red.

	Dry nature											Agriculture		Urban			Other	
	Forest	(Semi) nat. Grassland	Heathland	Wetlands	Dunes (open)	Dunes (vegetated)	Salt marsh	Beach	Drift sand	Fresh water	Sea	Agriculture	Field borders	Built-up	Infra-structure	Public green space	Unpaved	unknown
Opening stock	**313,224**	**49,841**	**38,343**	**37,006**	**24,010**	**13,679**	**12,737**	**9,612**	**4,272**	**408,344**	**5,643**	**1,867,094**	**18,440**	**448,358**	**109,774**	**70,931**	**342,027**	**1,529**
Additions																		
From dry nature	4,634	4,063	6,501	5,186	2,541	4,034	158	605	569	3,140	2,407	19,681	5,284	3,496	1,659	1,536	11,752	71
From fresh wwater	227	536	167	570	1	0	0	0	194		59	667	71	1,045	296	177	1,196	136
From sea	0	0	0	0	357	0	614	2,511	1	1,160		0	0	47	74	0	857	22
From agricultural	8,423	19,955	732	8,418	16	0	1	0	119	6,095	0	5,516	22,644	18,860	7,027	1,828	83,738	178
From urban	2,665	805	156	442	54	1	0	6	126	2,227	16	11,428	321	6,275	2,332	2,132	22,939	57
From other	10,637	9,227	1,147	2,112	78	8	2	8	110	5,622	40	90,905	4,438	27,309	6,816	5,175	44	217
total additions	**26,586**	**34,586**	**8,703**	**16,728**	**3,046**	**4,044**	**774**	**3,130**	**1,120**	**18,244**	**2,523**	**128,197**	**32,757**	**57,033**	**18,204**	**10,849**	**120,526**	**681**
	8%	**69%**	**23%**	**45%**	**13%**	**30%**	**6%**	**33%**	**26%**	**4%**	**45%**	**7%**	**178%**	**13%**	**17%**	**15%**	**35%**	**45%**
Subtractions																		
To dry nature	6,343	5,126	4,042	4,150	4,464	2,278	649	233	1,005	1,695	3,483	34,588	3,076	1,849	617	1,789	23,219	109
To fresh water	605	1,158	143	866	140	38	1	12	178		1,160	5,720	375	1,097	652	479	4,426	1,197
To sea	0	0	0	3	140	4	445	1,812	2	59		0	0	4	12	0	28	12
To Agriculture	7,992	15,192	1,017	724	1	0	8	0	30	737	0	22,644	5,516	9,260	1,770	718	95,305	38
To urban	3,696	856	124	43	219	618	867	83	186	1,519	121	27,387	329	3,658	2,848	4,232	39,205	95
To other	5,921	4,304	228	280	44	497	402	39	108	1,332	879	82,591	1,325	13,597	5,879	3,520	217	44
Total subtractions	**24,558**	**26,637**	**5,553**	**6,066**	**5,007**	**3,435**	**2,372**	**2,179**	**1,510**	**5,342**	**5,643**	**172,930**	**10,622**	**29,466**	**11,778**	**10,738**	**162,400**	**1,495**
	8%	**53%**	**14%**	**16%**	**21%**	**25%**	**19%**	**23%**	**35%**	**1%**	**100%**	**9%**	**58%**	**7%**	**11%**	**15%**	**47%**	**98%**
Net change	2,028	7,949	3,150	10,663	-1,961	609	-1,598	951	-391	12,901	-3,120	-44,732	22,136	27,567	6,426	111	-41,875	-814
	1%	16%	8%	29%	-8%	4%	-13%	10%	-9%	3%	-55%	-2%	120%	6%	6%	0%	-12%	-53%
Closing stock	**315,252**	**57,790**	**41,493**	**47,669**	**22,049**	**14,288**	**11,138**	**10,563**	**3,882**	**421,246**	**2,523**	**1,822,362**	**40,576**	**475,925**	**116,200**	**71,042**	**300,153**	**715**

3 Species diversity

The second level of biodiversity is at the species level. Typical species diversity indicators are the total number of species that inhabit an ecosystem, their abundance (both absolute and relative to a 'natural' reference level), their spatial distribution, whether they are threatened, etc. In this section several of these indicators are collected, and processed to generate data for SEEA-EEA accounting tables.

3.1 Threatened species

Species decreasing in population size and/or in distribution range are placed on a Red List of threatened species. The Dutch Red Lists may be regarded as a national application of the IUCN Red List (IUCN 2008), but follows its own protocol. Red Lists are assembled and updated approximately every ten years for a number of species groups, based on the Red List status per species. As species continue to decline and become increasingly rare, they are categorized as "*Near Threatened*", "*Vulnerable*", "*Endangered*", "*Critically Endangered*", or "*Extinct*" (CLO 1052).

To date, official Red Lists of 18 species groups have been commissioned by the Ministry of Nature (in their various incarnations) and compiled by the various NGOs involved with monitoring of species groups, as. The Red list status of each evaluated species is published in the Dutch Government Gazette. Of most of these 18 species groups, the Red List status per species has been revised and published in the Government Gazette for a second time, resulting in updated Red Lists (CLO 1052). See Table 3 for an overview.

Of each of the 18 species groups, at least one third of the species in that group are on the Red List, with much higher ratios found in some of the species groups. With 19 out of 20 species being listed, almost all stoneflies have an unfavorable Red List status (see table). Approximately two thirds of the species of reptiles, butterflies, mayflies and mushrooms are on the Red List. Species groups of which relatively high proportions of the species have disappeared from the Netherlands include stoneflies, butterflies, mayflies and bees. Many threatened species are not protected by law (CLO 1052).

Periodical revisions of Red Lists make it possible to derive trends in the numbers of threatened species over time. However, with a revision frequency of approximately every 10 years, such trends do not reflect the actual situation in the years between revisions. By constructing 'virtual' Red Lists in the years between official Red List publications, it is possible to calculate the trend in the number of threatened species on a yearly basis, using annual monitoring data. (see the Red List Indicator, Section 3.1.1) (CLO 1052).

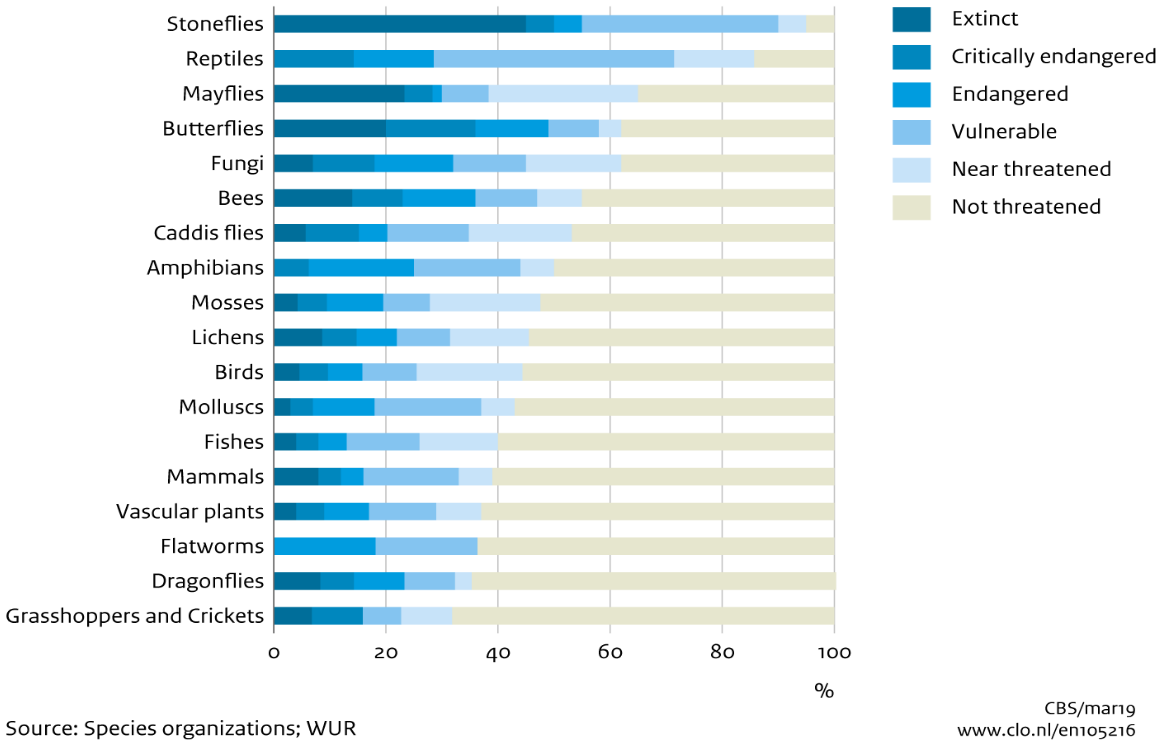

Figure 4. Percentage of threatened species per species group in The Netherlands, 2019 (adapted from CLO-1052)

Table 3. Update frequency of official Red Lists of threatened species.

	Group name	(in Dutch)	1995	2005	2009	2015	2017	2018	2019
Animals	Stoneflies	(Steenvliegen)		●					
	Reptiles	(Reptielen)	●	●	●				
	Butterflies	(Dagvlinders)	●	●	●				●
	Mayflies	(Haften)		●					
	Bees	(Bijen)		●				●	
	Caddis flies	(Kokerjuffers)		●					
	Amphibians	(Amfibieën)	●	●	●				
	Molluscs	(Weekdieren)		●					
	Fishes (fresh water)	(Zoetwatervissen)	●	●		●			
	Mammals	(Zoogdieren)	●	●	●				
	Birds	(Vogels)	●	●			●		
	Flatworms	(Platwormen)		●					
	Dragonflies	(Libellen)	●	●		●			
	Grasshoppers and Crickets	(Sprinkhanen en krekels)	●	●		●			
Plants	Macrofungi	(Paddestoelen)	●	●	●				
	Mosses	(Mossen)		●		●			
	Lichens	(Korstmossen)	●	●		●			
	Vascular plants	(Vaatplanten)		●		●			

3.1.1 Red list Indicator

The number of endangered species on the Red List can be regarded as an indicator for the state of the biodiversity in the Netherlands. Between 1950 and 1995, the number of endangered species has risen dramatically. About 50%[4] of all species considered gained Red List status during this period because they were endangered to some extent (CLO 1052; 1521).

The Red List Indicator (RLI) reflects changes in the number of species on the Red List and the degree to which they are under threat. The RLI includes seven species groups: mammals, breeding birds, reptiles, amphibians, butterflies, dragonflies and vascular plants. There are two RLI components: RLI *length* indicates changes in the number of species on Red Lists, while the RLI *colour* indicates the aggregated degree of threat for a species group. Both RLI components can be expressed as an index, using a value of 100 for the reference year 1995 (CLO 1521). See Section A.1 for methodological details.

The number of endangered species (Figure 5) has risen marginally between 1995 and 2005, but has in fact declined somewhat after 2005. In 2017, both the number of endangered species and the average level of threat appear to have risen again, indicating that the tendency towards biodiversity recovery is—at least temporarily—discontinued. (CLO 1521).

On average, since 1995 more species have shifted towards the less-endangered categories than to the more-endangered categories, although recently the average threat level has increased a little (CLO 1521).

Taking separate groups of species into consideration (Figure 6), it has been found that improvement is not restricted to vascular plants: since 1995, mammals and dragonflies have also improved. Although average threat status in 2017 of breeding birds and reptiles improved to some extent compared to 2005, the number of threatened species of these species groups is still the same (and higher compared to 1995). Other species groups show very little or no signs of recovery compared to 1995 Red List status (CLO 1521).

Individual species (groups) can be clustered in either terrestrial fauna and fresh water / wetland fauna. Trends in RLI for these two broad ecosystem types differ greatly. For fresh water / wetland fauna both Red List Length and Color improved since 2015, while for terrestrial fauna there is no such improvement (CLO 1573; Figure 7 and Figure 8).

During the accounting period 2005–2013, these results show a slight decrease from in Red List Length from 687 to 675 (−1.7%) endangered species. Note however, that this might as well be an effect of 2005 being the record year in the whole data period. Furthermore, there has been a slow decline in overall RL colour during the Accounting period 2005–2013, meaning a slight improvement in threat level. However, there are marked differences in changes per species group. The threat level for mammals, reptiles and dragonflies has been declined more than average, while the threat level for amphibians has been increased, also in absolute terms.

Given the infrequent updated of the (virtual) Red Lists prior to 2013, The significance of these small changes during the accounting period is uncertain. For future Accounts (e.g. 2013–2018), this will not be an issue.

[4] For the species considered in the Red List Indicator (CLO 1521), this is about 40%

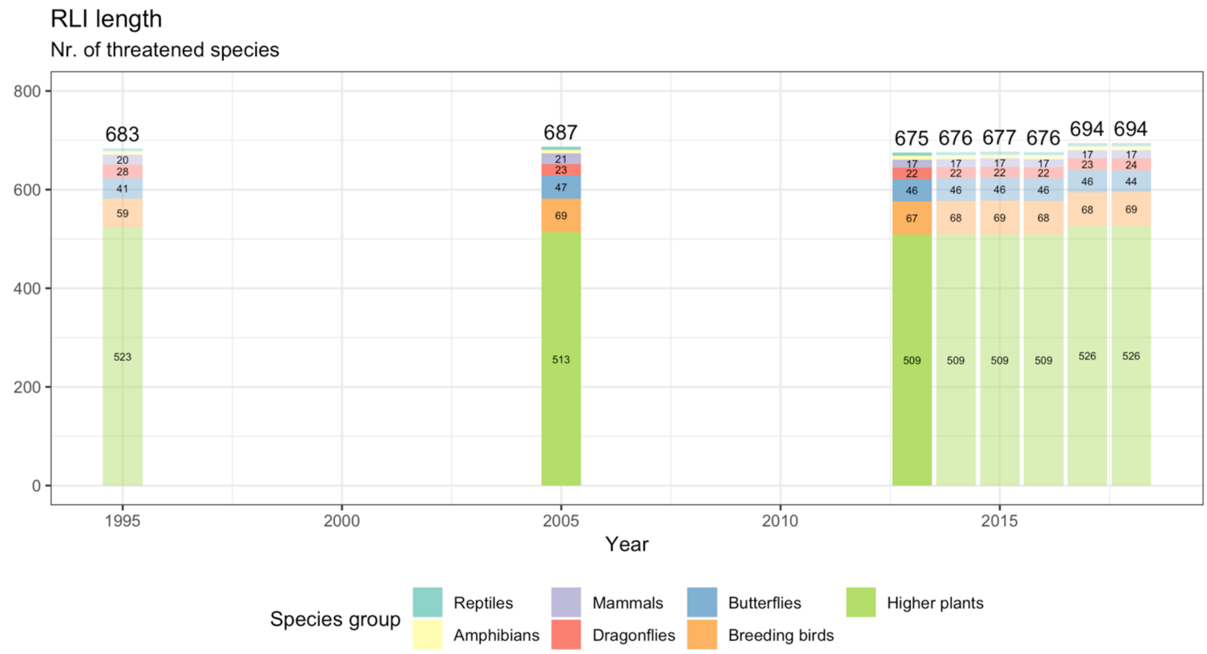

Figure 5. Red List lengths for seven species groups. Focal years 2005 and 2013 are highlighted.

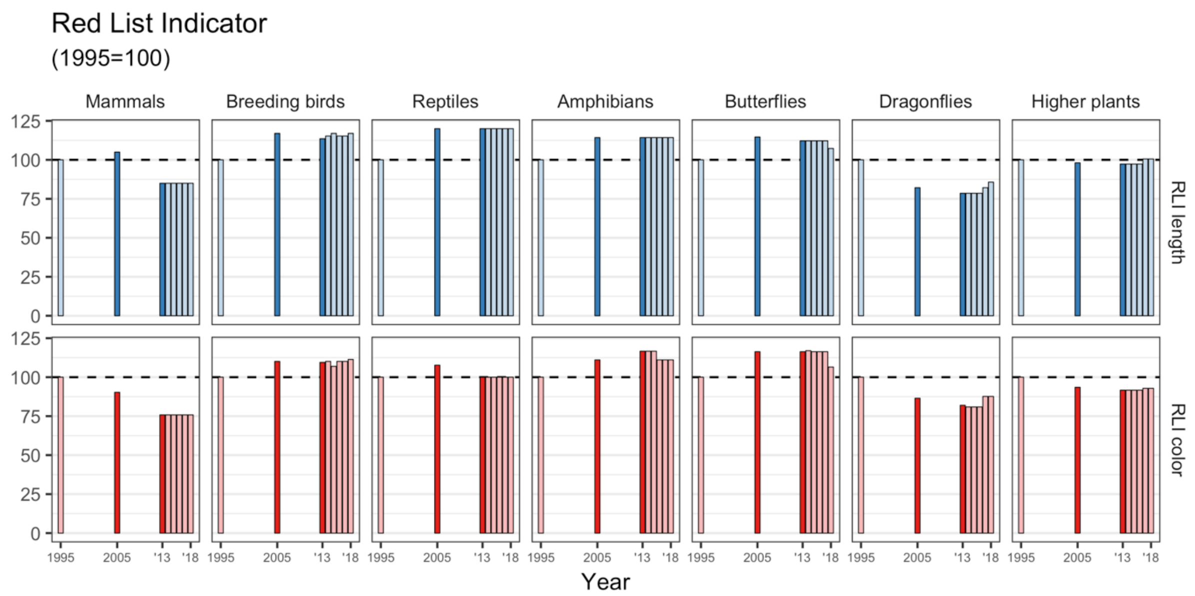

Figure 6. Red List Indicators per species group. Focal years 2005 and 2013 are highlighted

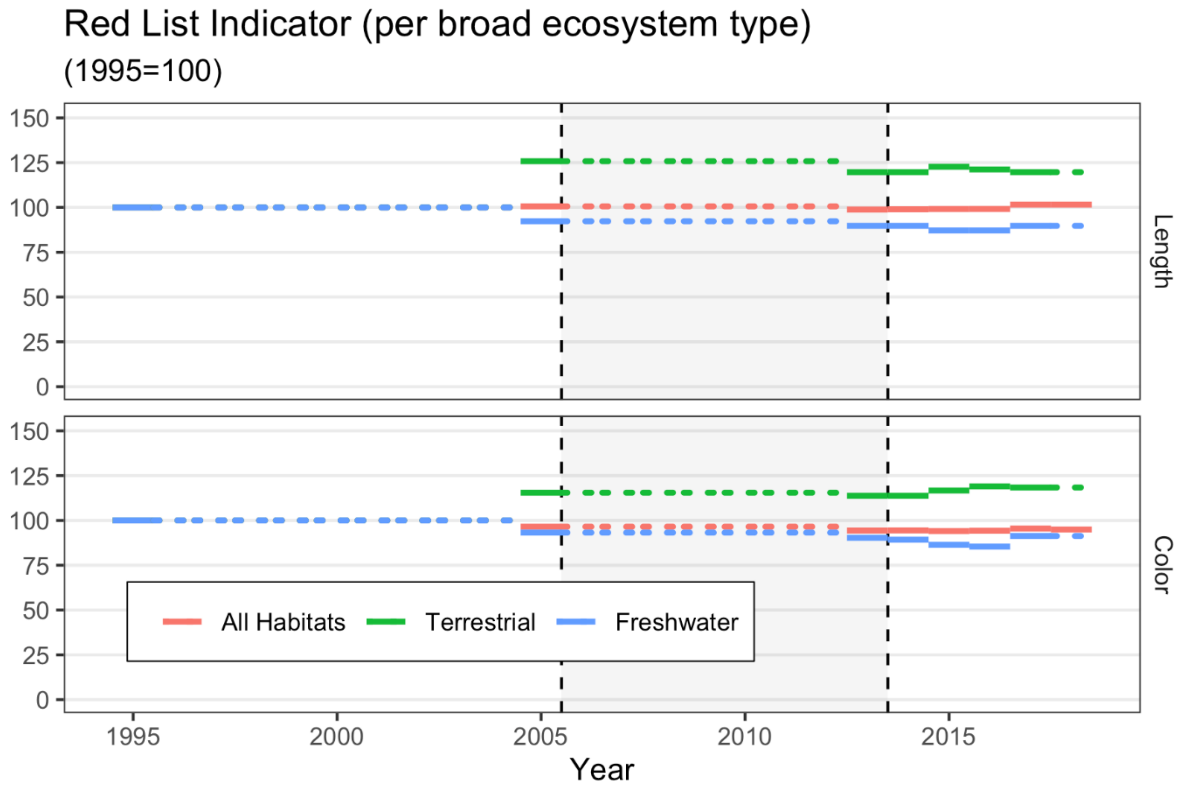

Figure 7. Red List Length and Color for all species considered, and for two major ecosystem types (terrestrial and freshwater/wetlands).

		All ecosystems		Terrestrial / dry nature		Freshwater / wetlands	
	Year	RL Length	RL color	RL Length	RL color	RL Length	RL color
	1995	100.0	100.0	100.0	100.0	100.0	100.0
Opening stock	**2005**	**100.6**	**96.5**	**125.8**	**115.5**	**92.3**	**93.2**
Net change		-1.8	-2.1	-6.1	-1.7	-2.6	-2.9
Closing stock	**2013**	**98.8**	**94.4**	**119.7**	**113.8**	**89.7**	**90.3**
	2014	99.0	94.5	119.7	113.8	89.7	89.3
	2015	99.1	94.1	122.7	116.7	87.2	86.4
	2016	99.1	94.3	121.2	119.0	87.2	85.4
	2017	101.6	95.5	119.7	118.4	89.7	91.3
	2018	101.6	94.9				

Figure 8. Red List Indicator account for 2005–2013. Indicator values for other years are included for reference.

3.1.2 Threatened species account

SEEA-EEA suggests the development of a threatened-species account to show the risk of extinction, in a format consistent with other accounts, i.e. columns to distinguish between the various risk levels, and rows to record the opening and closing stocks, and various type of mutations, such as additions to the Red List, or a change in Red List status (UN et al., 2014; Annex A, ¶A4.24).

Using the official Red List for 2005 and the virtual Red List for 2013, and a dedicated classification system to map changes in Red List status to account mutation types (See Section A.2 for methodological details), a threatened species account was developed (Table 4).

Table 4. Threatened species account for the Netherlands, 2005–2013. Grey cells denote logical impossibility.

	Red List categories							
	Extinct	Critically endangered	Endangered	Vulnerable	Near threatened	**Total Red List**	Least concern	**Total**
Opening stock (2005)	90	108	151	205	133	**687**	1084	**1771**
Additions								
Local extinctions	3					**3**		**3**
Rediscoveries of local extinct species		3	2	1	1	**7**	1	**8**
From lower threat categories		6	14	4		**24**	0	**24**
From higher threat categories			10	21	5	**36**		**36**
New additions to list		0	0	9	3	**12**		**12**
Removals from list							24	**24**
Total additions	3	9	26	35	9	**82**	25	**107**
Reductions								
Local extinctions		2	0	0	0	**2**	1	**3**
Rediscoveries of local extinct species	8					**8**		**8**
To lower threat categories		10	21	5		**36**		**36**
To higher threat categories		0	6	14	4	**24**		**24**
New additions to list							12	**12**
Removals from list		0	1	12	11	**24**		**24**
Total reductions	8	12	28	31	15	**94**	13	**107**
Closing stock (2013)	85	105	149	209	127	**675**	1096	**1771**

One conclusion that is directly clear from this account is that the total number of mutations is much larger than the net change in Red List length. Most mutations indicate a simple change in Red List status, followed by additions and removals from the Red List, and finally extinctions and rediscoveries. From the raw status transition data (Figure 23, in Section A.2), it is clear that most of the status changes are relatively minor (i.e. one 'step'), and that the numbers of transitions decrease with the 'distance' between RL status classes.

3.2 Living Planet Index

The Living Planet Index (LPI) is widely used in the international context to describe changes in biodiversity over time (WWF, 2014; CLO-1569). The rationale of the LPI is that the more species show negative population trends and the stronger the overall decrease is, the more deplorable the state of nature is (and vice versa).The LPI of the Netherlands reflects the average trend of 361 species of mammals, breeding birds, reptiles (CLO 1384), amphibians, butterflies, dragonflies and fresh water fish together for which sufficient data is available to calculate trends with (WWF Netherlands, 2015; van Strien et al., 2016).

Besides the overall LPI (CLO-1569; Figure 9), indices are available for the individual species groups, and specific habitat-related sub-groups (Figure 10 and Figure 11 and Table 5).

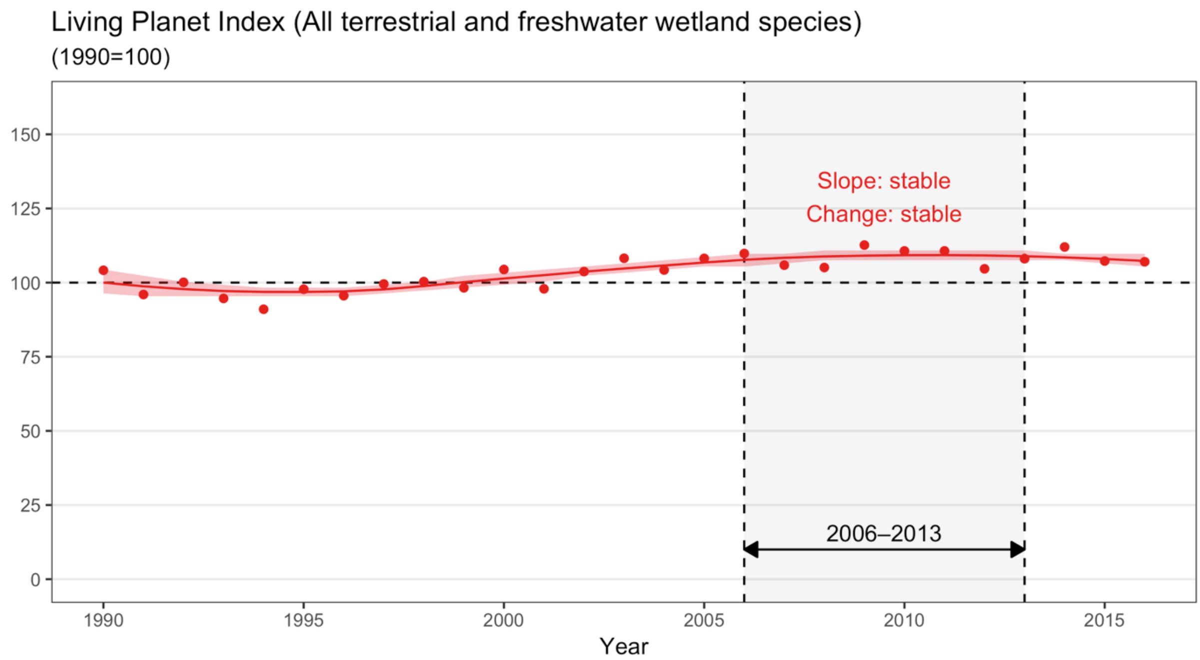

Figure 9. Living Planet Index for the Netherlands, total of all terrestrial, freshwater and wetland ecosystems. Points indicate the index value for individual years, while the solid line indicates a smoothed trend and it's associated 95% confidence band.

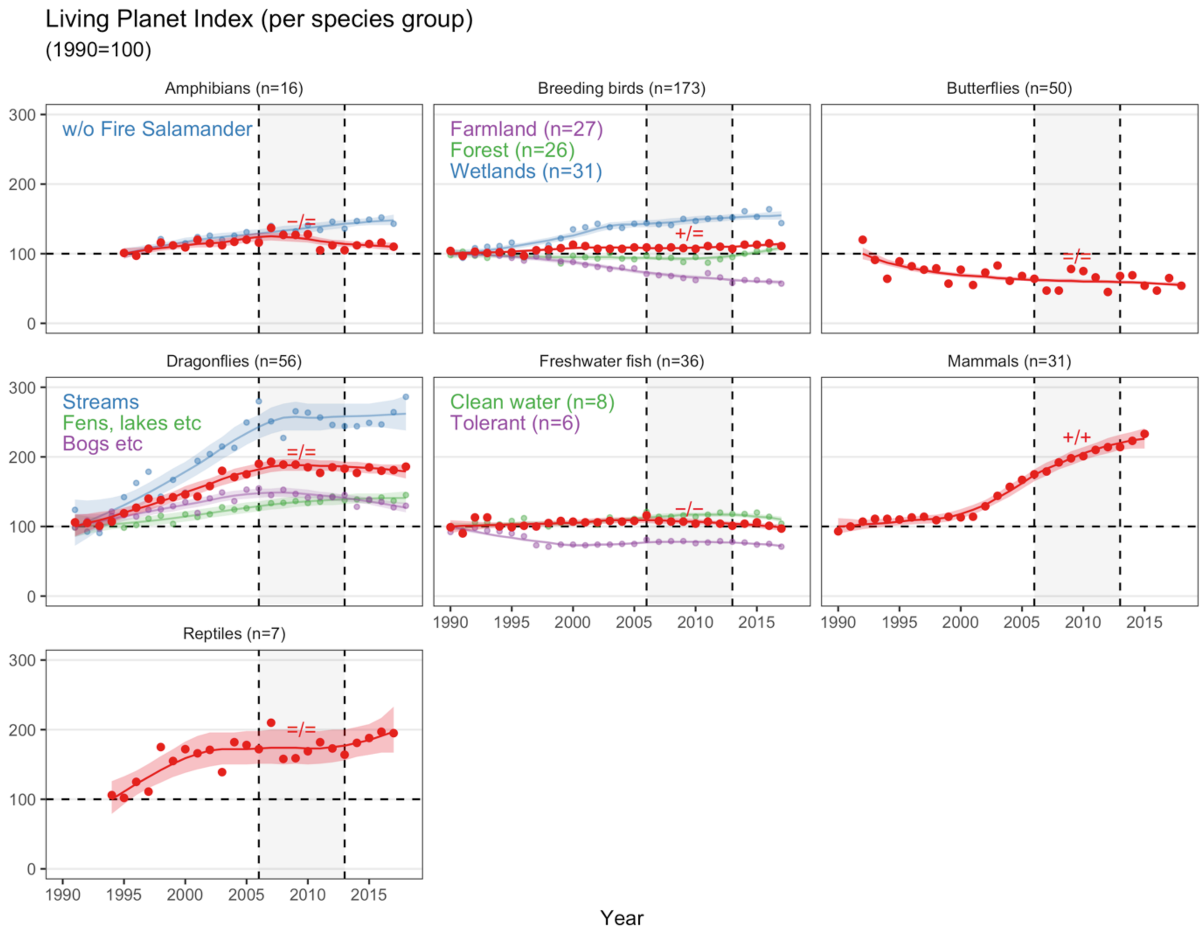

Figure 10. LPI for individual species groups (in red) and for selected habitat-specific sub-groups (other colors). Symbols like "+/=" indicate the trend during the focus period (first symbol) and comparison between 2005 and 2013 (second symbol). Symbols indicate an increase (+), decrease (−), stable (=), or uncertain(?).

Table 5. Trend estimates for all LPI indicators, for the accounting period (in red) and other time intervals.

		CLO ID	nr. species	Whole data period 1990–2018 CLO-trend	trend	change	Pre-accounting period 1990–2006 trend	change	Accounting period 20016–2013 trend	change	Post-accounting 2013–2018 trend	change	Last 10 yr 2008–2018 CLO trend
Overall LPI terrestrial and freshwater		1569	361	+	+	+	+	+	=	=	=	=	=
(Sub)-ecosystem type	Terrestrial	1579	215	–	–	–	–	–	=	=	=	=	=
	Nature areas	1581	84	–	–	–	–	–	=	=	=	=	=
	Forest	1162	36	=	+	+	–	=	+	=	=	=	+
	Open landscapes	1586		–	–	–	–	–	=	=	=	=	=
	Heathlands	1134	30	–	–	–	–	–	–	=	=	=	=
	Coastal dunes	1123	36	–	–	–	–	–	=	=	?	=	=
	Agricultural	1580	48	–	–	–	–	–	–	=	=	=	=
	Farmland birds	1479											
	Butterflies	1182		–									=
	Urban environments	1585	29	–	–	–	–	–	–	–	–	=	–
	Breeding birds												
	Butterflies												
	Freshwater and wetland	1577	141	+	+	+	+	+	=	=	–	=	=
(Sub-)species group	Breeding birds	1381	173	+	+	+	+	+	+	=	=	=	+
	Wetlands	1155	31	+	+	+	+	+	+	+	=	=	=
	Farmland	1479	27	–	–	–	–	–	–	=	=	=	–
	Forest	1618	26	=	=	+	–	=	=	=	+	+	+
	Freshwater fish	1578	36	=	=	=	+	+	–	–	=	=	=
	Clean water		8	+	+	+	+	+	=	=	=	=	=
	Tolerant		6	–	–	–	–	–	=	=	–	=	–
	Dragonflies	1387	56	+	+	+	++	+	=	=	=	=	=
	Streams			+	++	+	++	+	?	=	?	+	=
	Fens, marshes, etc			+	+	+	+	+	+	+	=	=	=
	Bogs etc			+	+	+	+	+	=	=	–	=	–
	Butterflies	1386	50	–	–	–	–	–	=	=	=	=	–
	Mammals	1571	31	+	++	+	+	+	+	+	?	=	+
	Amphibians	1077	16	=	+	=	+	+	–	=	=	=	-
	w/o Fire Salamander		15	+	+	+	+	+	+	=	=	=	+
	Reptiles	1384	7	+	+	+	+	+	=	=	?	+	=

Since 1990, the overall LPI indicator has increased by 7%, mainly because, during this period, mammal, reptile and dragonfly populations have grown. Over the past decade, the average trend of all species together has stabilized. The indicator reflects an average trend; various species and/or groups of species, in particular amphibians, butterflies and fish show a downward trend (CLO-1569).

To assess the changes in LPI during an accounting period two different approaches have been used. First, for each period the overall linear trend over this period can be computed and interpreted in terms of increasing (+), decreasing (−), stable (=) or uncertain (?). Second, the LPI indicator value during the closing year of the accounting period can be compared with the opening year so see if there is an increase, a decrease or stability. Both methods take uncertainties into account and only signal increases or decreases if these are significant at the p=0.05 level. See Section A.3 for full methodological details.

The first ('slope') method is the traditional ecological interpretation of trends in population time series, while the second ('change') method might be better aligned with the requirements of accounting tables, i.e. distinguishing between stocks and mutations, and a closed balance.

It is important to note that both methods are not based on the 'raw' annual LPI values *directly*, but employ a form of smoothing as an intermediate step to distinguish the trends from the contingent annual values. Again, see Section A.3 for full methodological details.

For the accounting period 2006–2013 the overall LPI is considered *stable* (both slope and change), starting at the lowest value of 107.7 in 2006, reaching a maximum of 109.3 in 2011, and decreasing slightly to 108.9 in 2013, i.e. a total range of 1.6, which is not considered significant given the average 95% confidence interval in LPI of 3.4 during this period.

Trends in LPI for the individual species groups vary considerably. Trends in mammals have been increasing, trends in freshwater fish have been declining slightly and most other species groups have been remaining stable during the accounting period. For amphibians, the trends are strongly dependent whether Fire Salamanders are included or not. With this rare and critically endangered species included, the trend in decreasing, but the trend in the other 15 species in increasing.

Also, within species groups there is considerable variation. For breeding birds, where the overall trend during the accounting period is relatively stable, the trend in wetland birds in increasing while the trend in farmland birds in decreasing. For dragonflies, the most of the strong increases since reference year 1991 occurred before the accounting period, i.e. during the interval 1991–2006. During the accounting period, only for fens and lakes a significant increase has been detected.

3.2.1 LPI per ecosystem type

Apart from average trends per species group, LPI can also be used as a signaling tool for change in ecosystem quality. The quality in this case is measured in terms of presence/abundance of species typically associated with certain habitats, so called habitat specialists. If the LPI is broken down by ecosystem, it appears that the increase of the overall LPI is mainly attributable to population increases of species typically associated with fresh water and marshlands. In farmland and open natural areas (heathland, dunes and semi-natural grassland), the average trend of the habitat specialists decreased, sometimes strongly. In woodlands, the LPI remained largely stable. (CLO-1569; Figure 11).

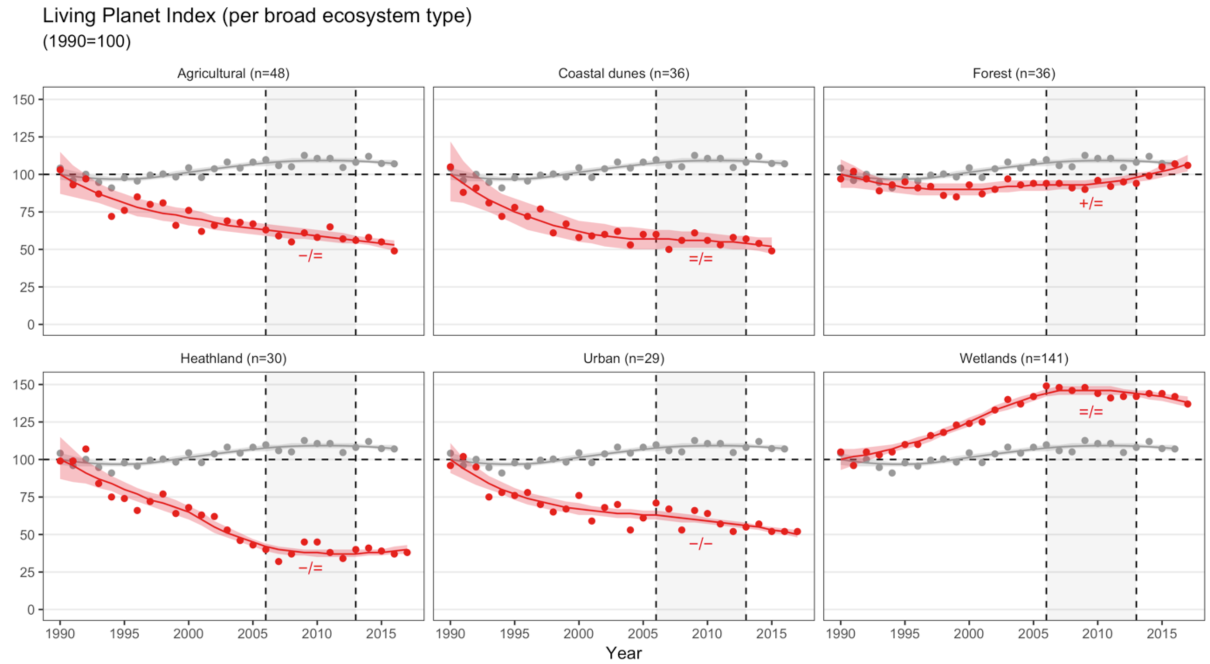

Figure 11. Living Planet Indices for six broad ecosystem types. The overall LPI is plotted in grey for reference purposes. −/=/+ indicate decreasing/stable/increasing trends/changes during the accounting period.

Agricultural areas

Trends in breeding birds, mammals and butterflies, that are characteristic for agricultural areas have on average been declining since 1990. 25 of 48 species have negative trends, while 9 have a positive trend (CLO-1580).

Populations of breeding birds typical of agricultural areas in the Netherlands are dwindling. The “Farmland Bird Indicator” (FBI) has declined by 30% since 1990. A historical reconstruction of farmland bird populations even shows a decline by more than 50% since 1960. Recently, the population decline has slowed, but not halted, despite focused policy measures. This Dutch farmland bird indicator is the national equivalent of the similar FBI indicator of the European Union. Whereas in the EU FBI 39 breeding birds are covered, for the Dutch FBI, 27 species frequently found in the Netherlands were selected (CLO 1479).

Populations of butterflies that are characteristic for agricultural and semi-natural grasslands have been declining. Of the 14 species included for this habitat, 4 have positive trends and 9 have negative trends (CLO-1181).

Forest

The trend in LPI for forest ecosystem species is on average stable since 1990, with a marked increase during the last decennium. This increase is mainly in populations of breeding birds and mammals.

Populations of butterflies that are typical for forest ecosystems have been both increasing (18 species) and decreasing (11 species) (CLO 1162).

Urban environments

On average, the population of urban fauna species (breeding birds and butterflies) has been declined with about 50%. This overall decline is mainly attributed to the decline of urban breeding bird populations. The population of typical butterflies has been stable during this period (CLO-1585).

Fresh water and wetlands

Overall, there has been a strong increase since 1990 in population sizes of characteristic wetland fauna. Of the 141 species of fish, breeding birds, amphibians, dragonflies, mammals and butterflies, 74 species have been increasing in population size, and 38 have been decreasing. The last decade this trend has been stabilized (CLO-1577).

3.2.2 LPI Account

To present LPI biodiversity indicators in a form consistent with SEEA-EEA an LPI account has been developed. The account approach requires the identification of opening and closing stocks, and the various mutations during the time interval. For an LPI account a similar procedure has been followed as for the threatened species account (Section 3.1), using smoothed values for the opening and closing years, rather than the 'raw' LPI values for these years. Again, this is to detect trends rather than the unavoidable interannual variations that are have no direct ecological meaning.

The resulting accounting table is presented in Table 6, listing LPI values and changes during the accounting period 2006–2013 for both the Netherlands as a whole and selected broad ecosystem types. Most of the changes in LPI are small and insignificant. Only for *Forest* there is a significant increase in LPI. LPI for *Heathland*, *Agricultural* and *Urban environments* are declining.

Table 6. LPI Account for the Netherlands, 2006–2013. LPI values for opening and closing years are smoothed values. The change assessment is taking uncertainty in these smoothed values into account.

		Living Planet index		Change in LPI		
Ecosystem (sub)type	CLO	2006	2013	Absolute	Relative	Assessment
All Terrestrial and Freshwater	1569	107.7	108.9	1.21	1%	Stable
Terrestrial	1579	85.0	87.0	2.0	2%	Stable
Terrestrial nature	1581	59.0	60.0	1	2%	Stable
Forest	1162	93.0	98.0	5	5%	Increasing
Open nature	1586	39.0	38.0	-1	-3%	Stable
Heathland	1134	42.0	37.0	-5	-12%	Decreasing
Coastal Dunes	1123	57.0	54.0	-3	-5%	Stable
Freshwater and wetlands	1577	144.0	144.0	0	0%	Stable
Agricultural	1580	63.0	56.0	-7	-11%	Decreasing
Urban	1585	63.0	56.0	-7	-11%	Decreasing

3.3 Ecosystem quality

A second approach to assess the ecological quality of ecosystems based on species abundance data is to relate these to a reference quality of ecosystems. In the ideal case this reference should be the undisturbed, pristine stats of ecosystems. In reality, given the prolonged and often defining impact of humans on nature in the Netherlands, such a state is often highly hypothetical. Examples are semi-natural grasslands that were formed by extensive land use, heathlands, formed by sheep grazing, and drift sand areas which are actually highly degraded 'scars' resulting from past overgrazing or burning. Therefore, the ecosystem quality, in terms of species present and their abundances, of 1950 is used as a reference. This year was well before agricultural intensification led to ecological pressures, such as eutrophication due to artificial fertilizer, habitat fragmentation due to large-scale land reforms and ecological desiccation due to increased drainage.

In the Netherlands, this approach has been applied systematically to a selected set of ecosystem types, using monitoring data for in total 457 species, selected from breeding birds, butterflies, reptiles and vascular plants. Ecosystem-scale indices are expressed as a 'mean species abundance', which is the average abundance for all species, each scaled to a value of 100 for the 1950-level abundance and capped at that level to prevent that species that do very well under present anthropogenic conditions compensate for species that don't. This indicator is named *mean species abundance* (MSA) (Reijnen et al, 2010).

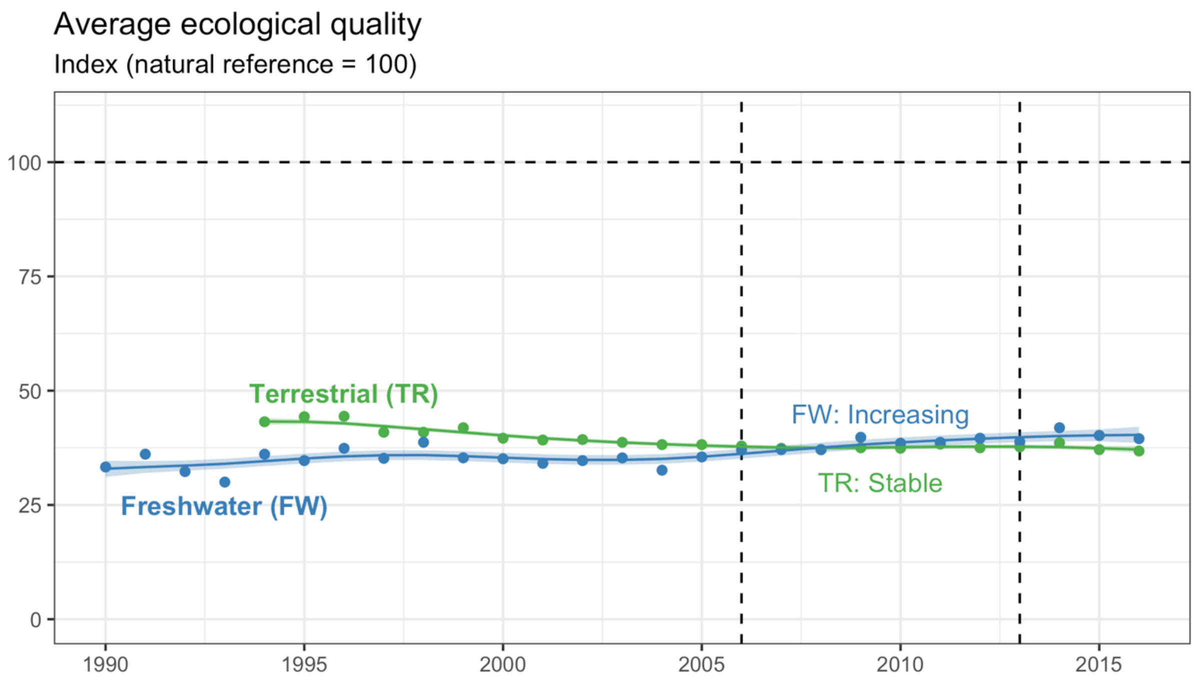

Figure 12. Average ecological quality on an aggregated level, for both terrestrial and freshwater nature, expressed as the mean species abundance index (MSA), using 1950 as a reference level. Labels 'increasing' and 'stable' refer to changes within the accounting period 2006–2013, as indictated by dashed lines. Based on CLO-2052.

Monitoring data for a group of characteristic species and target species per ecosystem (Figure 12 and Figure 13) indicate that the average quality of terrestrial ecosystems has declined since 1994. Over the last ten years or so the average ecological quality of ecosystems has not decreased, but has not increased significantly either. This picture is consistent with the trend in animal species in terrestrial ecosystems. The trend differs for each type of ecosystem. The decline in the quality of heathland and wetland ecosystems has been halted, whereas the quality of open dunes is still declining. The quality of semi-natural grassland and forest ecosystems has on average been stable between 1994 and 2017 (CLO-2052).

The trend in ecological quality of freshwater ecosystems has on average been more positive than for terrestrial ecosystems. The ecological quality of freshwater ecosystems improved slightly between 1990 and 2016 as measured by the occurrence of macrofauna and water plant species, based on the Water Framework Directive (WFD) quality standards. The quality measures based on the occurrence of water plants and macrofauna have both increased, especially in streams and canals. This improvement has not been found in all water ecosystems. There has been hardly any improvement in the occurrence of water plants in ditches, while the occurrence of macrofauna in lakes has decreased (CLO-2052).

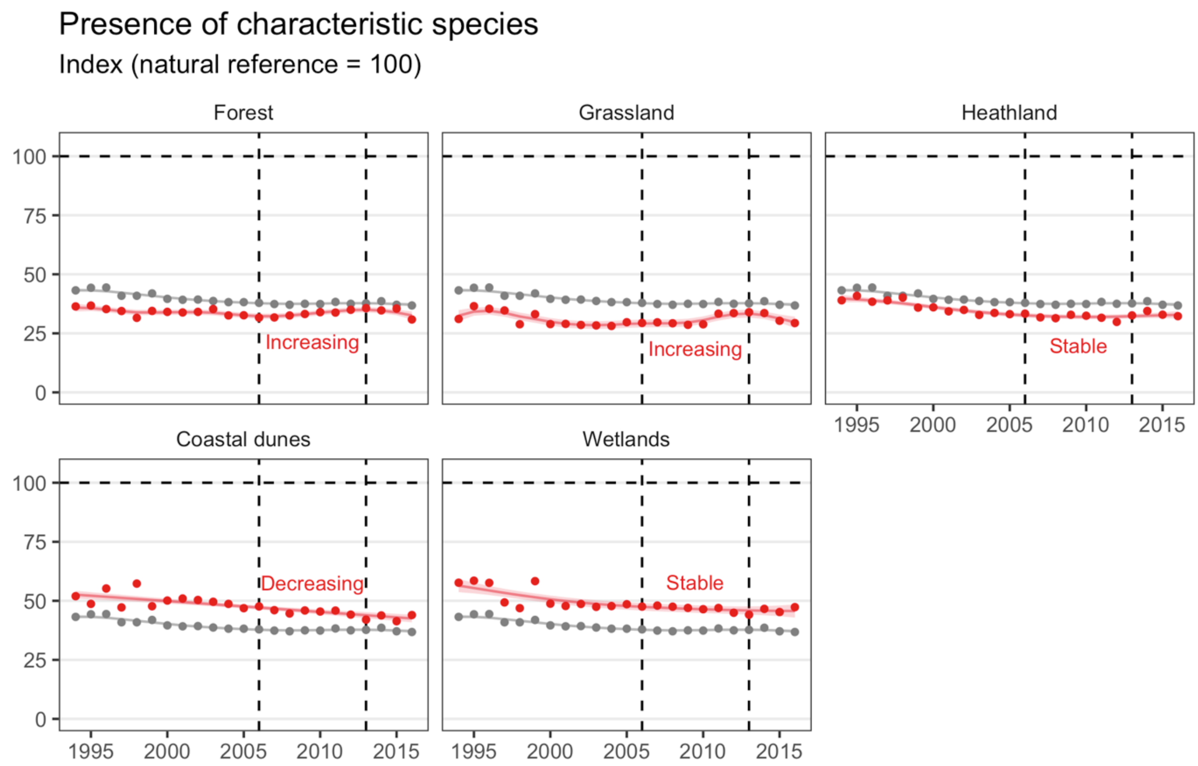

Figure 13. Average ecological quality for selected terrestrial ecosystems, in red (terrestrial aggregate in gray for reference). Text labels refer to the change assessment during the accounting period. Based on CLO-2052.

3.3.1 Ecosystem quality account

Changes in ecological quality, expressed as Mean Species Abundance (MSA) during the ecosystem accounting period 2006–2013 have been analyzed similarly as for the Living Planet Index (LPI). The results () indicate that from the 5 terrestrial ecosystems 2 are stable, 2 are increasing in quality and 1 is decreasing in quality. These assessments are strictly valid for the 2006–2013 period only. On the longer time scale both forest and semi-natural grassland are stable in terms of quality.

Table 7. Ecosystem quality account for 2006–2013, based on MSA data for five terrestrial ecosystem types (and their aggregate) and freshwater. The long-term trend assessment is based on CLO-5052.

Ecosystem	**MSA**		**Change**			**Long term trend**
	Opening	Closing	absolute	relative	interpretation	(1994–2017)
Terrestrial						
overall	37.8	37.8	0	0%	Stable	Decreasing/Stable
Forest	32.3	35	2.7	8%	Increasing	Stable
Grassland	29.2	33.4	4.2	14%	Increasing	Stable
Heathland	32.6	32.3	-0.3	-1%	Stable	Decreasing/Stable
Coastal dune	47.1	43.9	-3.2	-7%	Decreasing	Decreasing
Wetlands	47.5	45.9	-1.6	-3%	Stable	Decreasing/Stable
Freshwater						
overall	36.2	39.8	3.6	10%	Increasing	Increasing

3.4 Biodiversity account

Information on ecosystem extent (Section 2.2.1) and species abundance (Sections 3.2 and 3.3) can be combined into an overall biodiversity account (Table 8). In most cases the LPI and MSA indicators agree. Especially for heathland they don't agree, with LPI declining but MSA remaining stable. Inspection of the graphs for both indicators suggests that this disagreement is mainly due to the developments prior to the opening year 2006, where LPI decreased from 100 to ≈40, while MSA remained reasonably stable during the whole data period.

Table 8. Combined ecosystem account, integrating information on ecosystem extent and biodiversity indicators.

Ecosystem (sub)type	Extent			Living Planet index				MSA ecosystem quality			
	2006	2013	Change	2006	2013	Change	assessment	2006	2013	Change	assessment
All Terrestrial and Freshwater				107.7	108.9	1%	Stable				
Terrestrial				85	87	2%	Stable				
Terrestrial nature				59	60	2%	Stable	37.8	37.8	0	Stable
Forest	326903	329540	1%	93	98	5%	Increasing	32.3	35	8%	Increasing
Open nature				39	38	-3%	Stable				
Heathland	38343	41493	8%	42	37	-12%	Decreasing	32.6	32.3	-1%	Stable
Coastal Dunes	24010	22049	-9%	57	54	-5%	Stable	47.1	43.9	-7%	Decreasing
Semi-natural grassland	49841	57790	14%					29.2	33.4	14%	Increasing
Freshwater and wetlands				144	144	0%	Stable				
Freshwater	408344	421246	3%					36.2	39.8	10%	Increasing
Wetlands	37006	47669	22%					47.5	45.9	-3%	Stable
Agricultural	1867094	1822362	-2%	63	56	-11%	Decreasing				
Urban	519289	546967	5%	63	56	-11%	Decreasing				

Notes:

Forest' includes permantenly vegetated coastal dunes

Urban' includes built-up environments and public green space

4 Experimental spatial indicators

Disclaimer: this Section is experimental. It is not based on officially published data. It serves as an illustrative example of how occupancy modelling might be used to yield highly structured spatial information on biodiversity for SEEA-EEA reporting purposes.

Spatially explicit biodiversity indicators have two important applications for spatial biodiversity indicators. First, they provide spatial information for the biodiversity account itself, allowing for a regional-scale assessment. Second, they provide spatial information for the ecosystem condition account, which, in the ideal case, provides condition indicators for each individual ecosystem asset.

In the Netherlands, the use of spatially explicit biodiversity indicators for ecosystem accounting purposes has been pioneered by Remme et al. (2016) who developed maps of species richness for various species groups for the province of Limburg. Here, we build upon this earlier work by developing annual maps of species distribution and -richness for the whole of the Netherlands.

Trends in spatial distributions of species can be considered the ‘extent’ of species. These trends are not synchronous with trends in species abundance. While a species is declining in abundance, all sites or monitoring grid cells may still be occupied, especially when grid cells are large (typically 5x5 km). Only when the last individual within a site or grid cell disappears the distribution extent will decrease as well. Distribution extent is therefore less suitable for conservation purposes, especially when rare species are concerned. For increasing species this is reversed: when a new site becomes occupied by a few individuals this is immediately reflected in distribution extent, while the small increase in abundance may not be visible in population indices directly (Dutch Butterfly Conservation[5])

4.1 Butterflies

Occupancy modelling was used to develop a homogenous set of distribution maps for multiple species groups. Here, only the annual occupancy maps for butterflies are used (50 species, 1990–2017).

Occupancy data are available at two spatial resolutions: a basic resolution of 1x1km and an aggregated resolution of 5x5km, corresponding with the traditional monitoring grid. Even for the most common butterfly of the Netherlands, *Pieris rapae* (Klein Koolwitje) the maximum extent is only ≈60%, while in reality this species is found virtually everywhere. For this reason, the distribution extent for each species is based on the 5km occupancy probability data, using a probabilistic approach (See Section A.4.1 for methodological details)

Average distribution extent for all butterfly species during the accounting period clearly shows a bimodal distribution, with 14 ‘spatially common’ species with an extent of >80% of the terrestrial part of the Netherlands (when evaluated at the 5km scale), and 25 ‘spatially rare’ species with an extent of <20% (Table 9, see Table 12 in the Supplementary Information for full details)

[5] https://www.vlinderstichting.nl/vlinders/waarnemingen/waarnemingen-verzamelen

Table 9. Summarizing statistics of butterfly extent. Mean occupancy refers to the percentage of 5x5 km grid cells that is occupied during at least one year by a species. Based on species-specific data in Table 12.

Mean occupancy	Number of species
80–100%	14
60–80%	4
40–60%	4
20–40%	3
0–20%	25

For each butterfly species the temporal trend in extent was determined. Because some species occur everywhere, and some other species are confined to a small region, these trends are expressed as relative values, from 0 nowhere to 1 if the species is present in all grid cells where the species has ever been found. The results (Figure 27, in the Supplementary information) show that most spatially common species (plotted first) are generally stable, while the more spatially rare species (plotted last) are more fluctuating and often decreasing in extent.

For all species, the change in relative extent during the accounting period 2006–2013 was analysed by first smoothing the time series of annual values, and then testing if the smoothed extent for 2013 was significantly different from the smoothed extent for 2006 (Figure 27, symbols; Table 12, rightmost column). Overall, 21 of 50 species remained stable during the accounting period, 15 increased and 14 decreased in extent. From the species with the smallest absolute extent (<10% of all land), 8 out of 21 species were declining in extent, with 5 of these species having a decline of >10% of their maximum extent.

Only a few species have a strongly increasing trend. *Argynnis paphia* (Keizersmantel; +33%), which was virtually disappeared from the Netherlands around 1980, but since then has shown a spectacular comeback (van Swaay et al., 2019); *Apatura iris* (Grote weerschijnvlinder , +26%), most likely due to a warming climate and older and better quality moist forest types (van Swaay and Poot, 2019); *Euplagia quadripunctaria* (Spaanse Vlag, +25%), which is expanding within a limited region (Southern Limburg)

An aggregated overall trend in butterfly distribution extent results suggests that all increases and decreases at the species level are averaged out and that the overall trend is *declining* during the whole 1990–2017 period for which data was available, but *stable*, during the accounting period (Figure 14). See Section A.4.4 for methodological details.

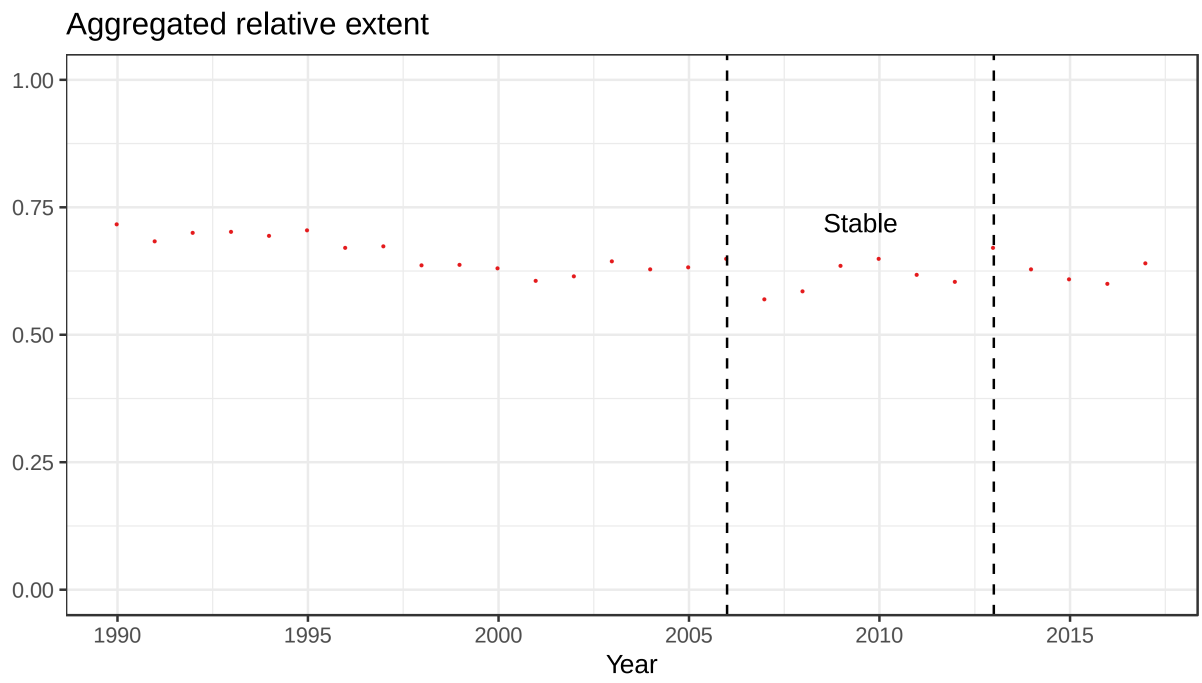

Figure 14. Overall (aggregated) trend in relative distribution extent, based on the unweighted average of relative extent time series for all 50 species.

4.2 Extent vs LPI

As mentioned previously in the introduction to this section, it is interesting to compare trends in spatial distribution (extent) with trends in abundance (e.g. LPI trends). In Figure 28 (in the Supplementary Information), times series for both indicators are plotted for all 50 species of butterflies. As for the extent analysis, changes during the accounting period 2006–2013 were analysed using smoothed values and the associated uncertainties.

The results show that the most common combination is that of 'stable' extent and abundance (15) followed by a 'stable' abundance and 'decreasing' extent (Table 10). Close inspection of the corresponding plots (Figure 28) reveals that most of these 'stable' abundance plots are at a relatively low absolute level, indicating that these species stabilized after a previous decrease in abundance. The current (i.e. during the accounting period) decrease in extent should thus probably be interpreted as suggested in the introduction, i.e. a loss in extent following a loss in abundance as a sign of overall decline and local (site-specific) extinction.

Unfortunately, the opposite cases where an increase in extent leads a later increase in abundance is not detected from these data, mainly because for most species with a strong increase in extent there was not sufficient monitoring data to determine reliable abundance indicators.

Table 10. Changes in distribution extent and abundance during the accounting period 2006–2013 for 50 butterfly species. Grey cells indicate similar changes

	Δ abundance				
Δ extent	**Increasing**	**Stable**	**Decreasing**	**Missing**	total
Increasing	2	8	2	3	15
Stable	3	15	2	1	21
Decreasing	0	10	4	0	14
total	5	33	8	4	50

Overall, during the accounting period, the change in extent was assessed as stable (Figure 14), while the change in LPI for butterflies was assessed as declining (Figure 10 in Section 3.2).

4.3 Species richness

A commonly used indicator of biodiversity is species richness, i.e. the number of species within a given site or any other spatial area. (Probabilistic) maps for species richness can be obtained from occupancy probability maps by combing the maps for individual species. See Section A.4.5 for methodological details.

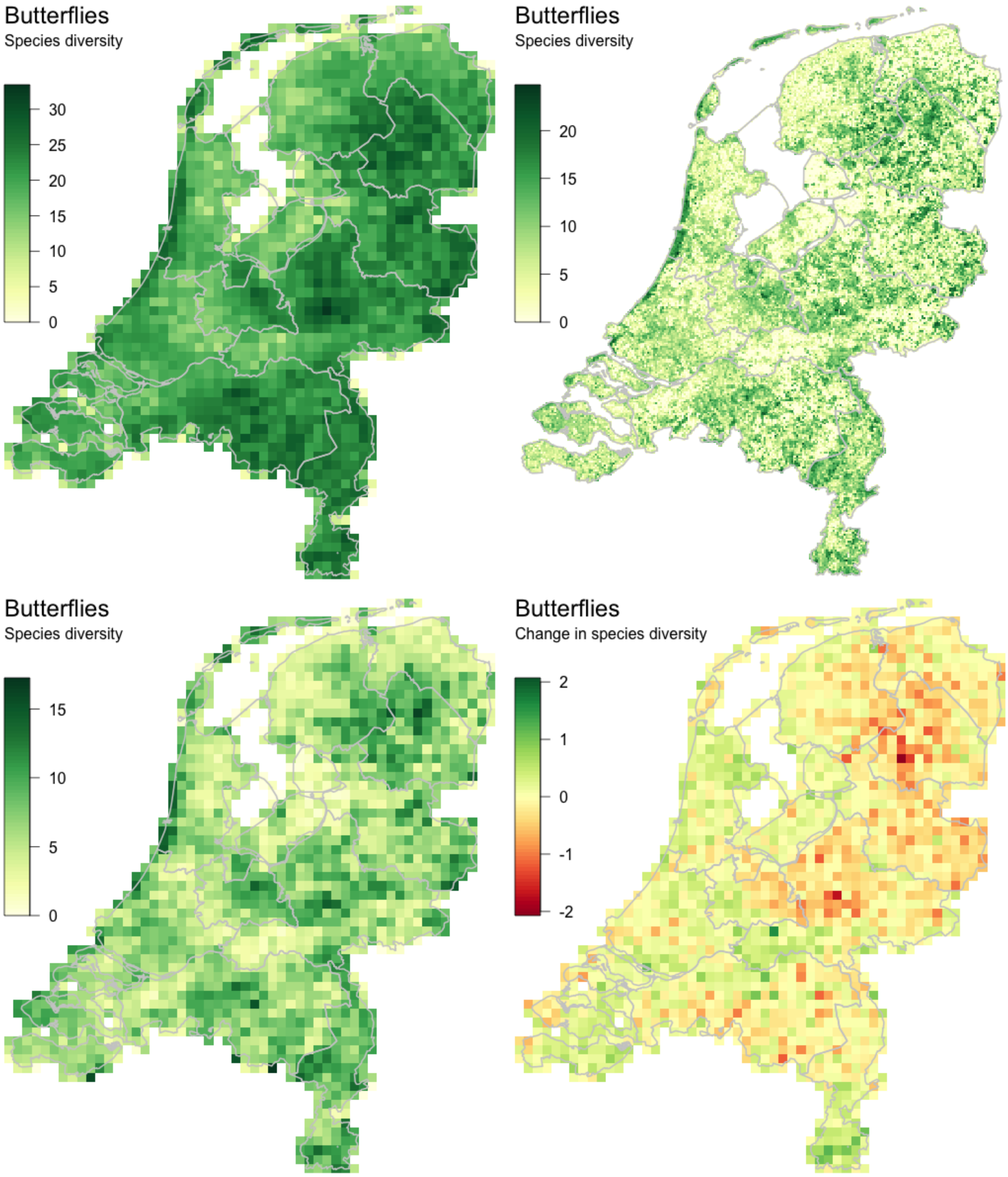

Figure 15. Butterfly species richness. Top left: based on 5x5km aggregated occupancy data. Top right, based on 1x1km occupancy data. Bottom left: Species richness aggregated from 1x1km to 5x5km. Bottom right: Changes in species richness (at 5km scale) during the accounting period 2006–2013. Grid cells where there was no significant change were reset to 0.

The results (Figure 15) clearly indicate the existence of large-scale spatial patterns in species richness, which on first sight reflects large-scale landscape structure, with low richness in areas with clay and peat soils and large-scale intensive agriculture, and high species richness mainly found in the coastal (dune) area and the southern and eastern part of the Netherlands where sandy soils prevail, and where the landscape is more a mosaic of agriculture and nature. This will be investigated more in detail in Section 4.4.5

These maps also clearly illustrate the scale-dependence of species richness. When the mapping is carried out at the 5km scale the median species richness is 20.5 and the maximum is 33.5 (out of 50). At the finer 1km scale these numbers are 6 and 25, respectively. This can be explained by the presence of more habitats (and their associated species) within a 5x5km grid cell, compared to a 1x1km grid cell. When this 1x1km species diversity map is aggregated to the same 5x5km, these numbers are 6 (median richness) and 17 (maximum). Thus, the *total* species richness at 5x5km scale is not equivalent to the *average* richness at that same scale.

4.3.1 Changes in species richness

Based on annual species richness maps, the change in species richness is determined by comparing maps for 2006 and 2013. As with previous change analysis, the raw annual time series were smoothed before a comparison was made, to distinguish true long-term changes from short-term fluctuations. The resulting map (Figure 15) shows coherent spatial clusters of increasing and decreasing species richness. In general, regions with declining species richness are “Veluwe”, “Twente”, “Drenthe”, and eastern “Brabant”. Most of these declining regions are found where richness is highest in general, but this relation is not vice-versa: regions like Southern Limburg and the coastal dunes also have a high species richness, but did not show any decline. Southern Limburg was one of the regions with the highest increase.

Overall, species richness increased in 19.8% of all 5km grid cells, decreased in 21.8% of the grid cells and remained stable in 58.4 of all grid cells. The mean change in richness (−0.03) is significant different from zero ($p < 0.01$).

4.4 Habitat-dependent species completeness

For five different habitats (Forest, Heathland, Coastal Dunes, Freshwater wetlands and Agricultural) a number of characteristic species have been identified (by Statistics Netherlands’s ecologists). These are the same species as used in the habitat-specific LPI indicators (3.2.1). The characteristic butterfly species have been listed in Supplementary Table 13. From this table, which uses the same extent-based ordering of species as in the other butterfly tables, it can be immediately seen than in the Agricultural habitat all characteristic species are fairly common, while for the more natural habitats the characteristic species have a (much) more limited spatial distribution. The Heathland habitat includes some of the most (spatially) rare species. Also note that the set of species that are characteristic for Coastal Dunes are a subset of that for Heathland (both are open natural areas). The number of characteristic species ranges between 6 (Forest, Coastal Dunes) to 13 (Heathland, Agricultural). The Freshwater Wetland habitat has only one characteristic butterfly species (but many dragonfly species) and is not further discussed here.

Based on the LCEU maps for the Netherlands, maps can be constructed showing the fractional coverage of these habitats, based on the corresponding Ecosystem Types. These maps (Figure 16) show the broad spatial distribution of these habitats. Forest has a strong concentration in the Veluwe area, and is widespread in Brabant, Twente, and Drenthe. Heathland is mostly found in the same regions where forest is found, with most areas in the Veluwe region and Drenthe. Coastal dunes are, well, found along the coast, and Agriculture is found everywhere except where large forests or urban environments prevail, although the northwestern provinces have a more intense agricultural cover than the southeastern part of the Netherlands

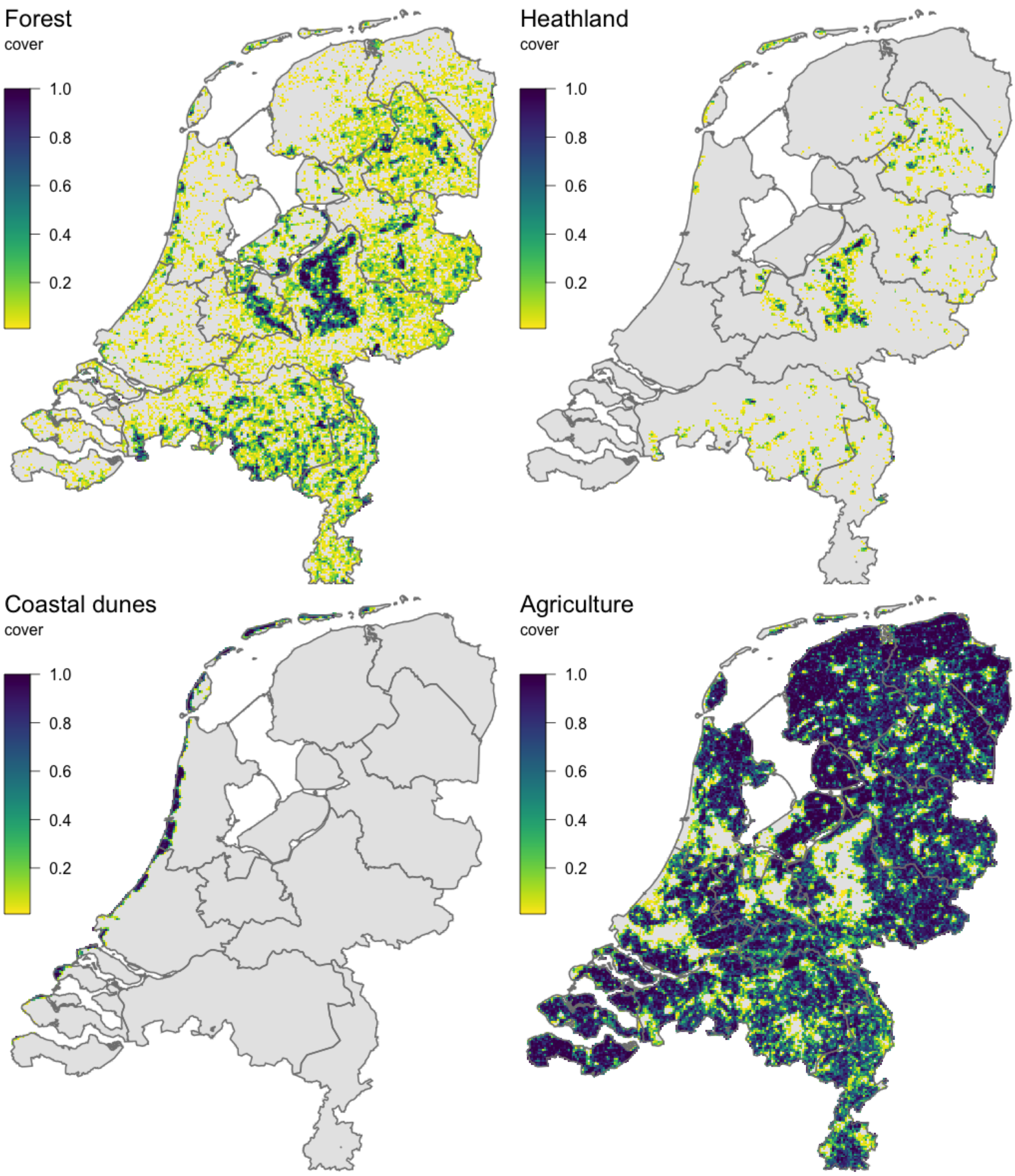

Figure 16. Fractional coverage of four butterfly habitats, based on the LCEU map of the Netherlands (for 2013)

For each of these habitats, habitat-specific species richness maps have been constructed by considering only those species that are characteristic for these habitats. This richness can be compared to the maximum richness (i.e., the number of characteristic species for that habitat) to derive a *completeness* indicator, which ranges from 0 (no characteristic species present) to 1 (all characteristic species present.

4.4.1 Forest

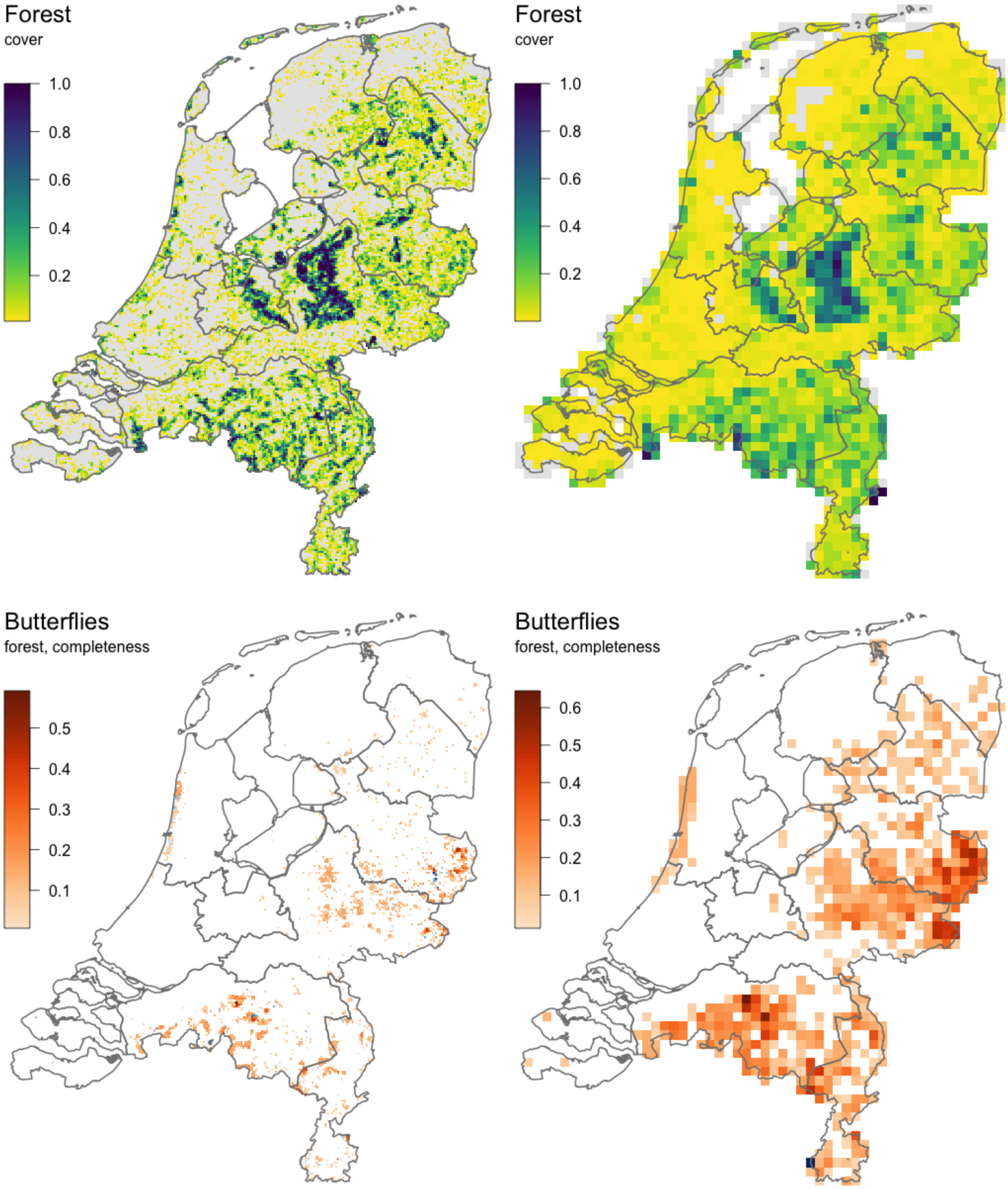

Figure 17. Distribution of Forest habitat within the Netherlands, and the relative species richness ('completeness') of forest-specific butterfly species. Maps are at two spatial scales, 1km (left) and 5km (right).

Forest completeness is maximal in Twente and Northern Brabant, but not in those locations where forest cover is highest, such as the Veluwe region

4.4.2 Heathland

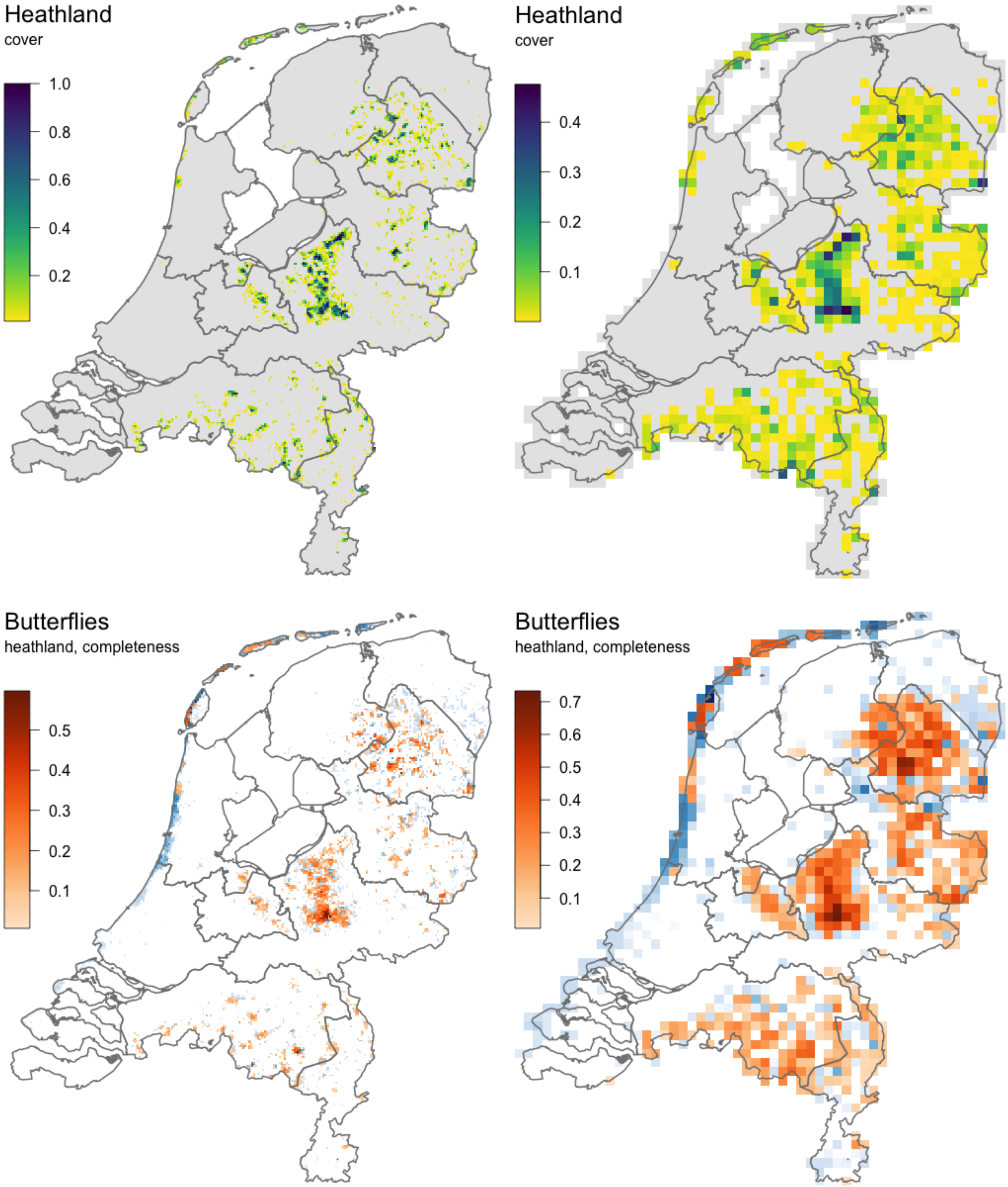

Figure 18. Idem, for Heathland. Heathland species completeness in grid cells with heathland habitat is colored in red. Heathland completeness within in other habitats is colored in blue.

Heathland species completeness is highest where extensive heathlands are found, especially where small wetlands are ample, such as in the southern Veluwe region (Deelense veld) and Drenthe (Dwingelderveld). Many heathland species are found within the coastal dunes as well, indicating that these species often prefer open natural landscapes, rather than heath as a specific vegetation type.

4.4.3 Coastal dunes

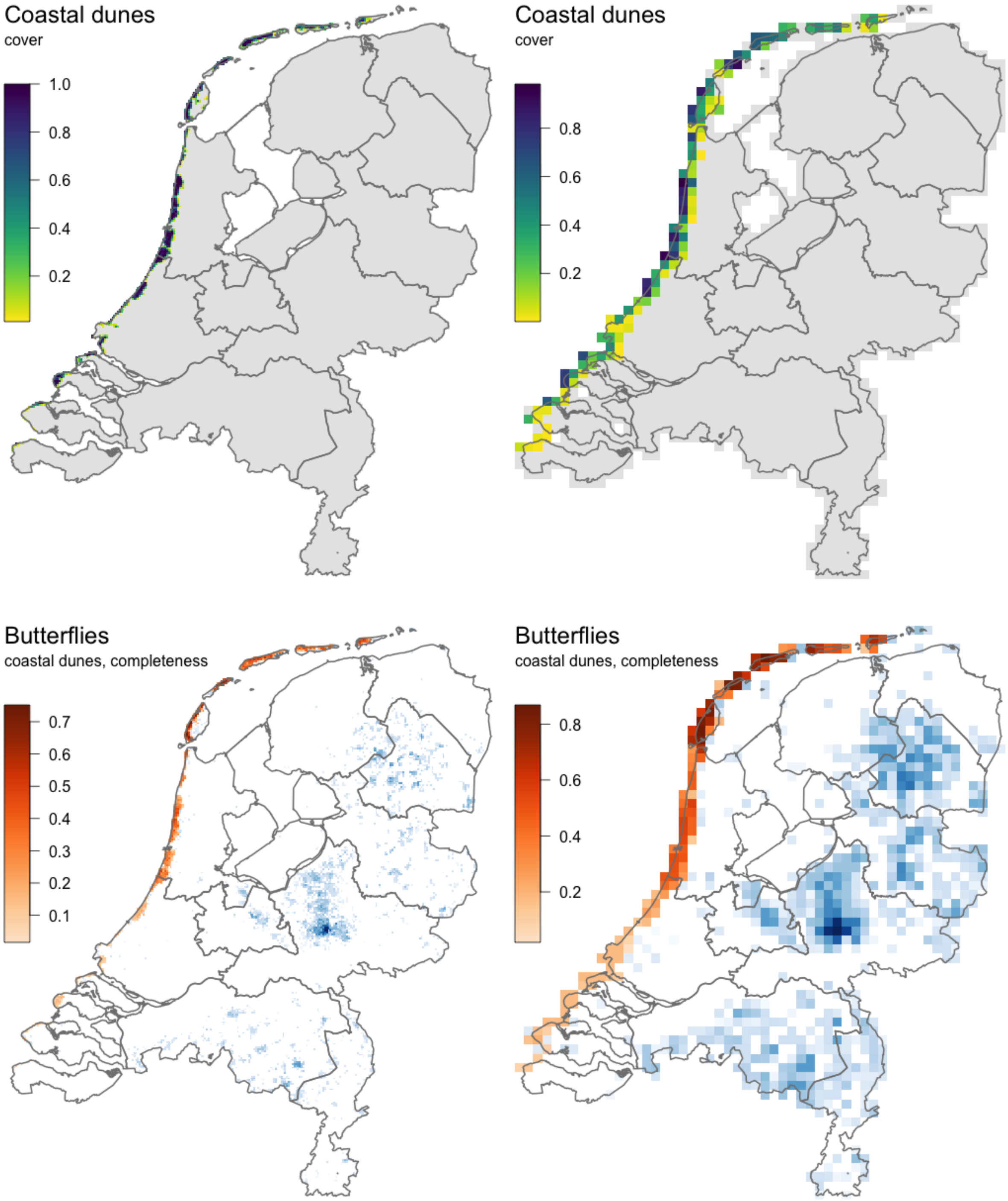

Figure 19. Idem, for Coastal Dunes.

Coastal dune specific species completeness shows a gradient from relatively low values within the southeastern dunes to highest values at the Wadden islands. Possible explanatory factors are the dune age, $CaCO_3$ content, N deposition, and the vegetation response to these drivers.

4.4.4 Agricultural

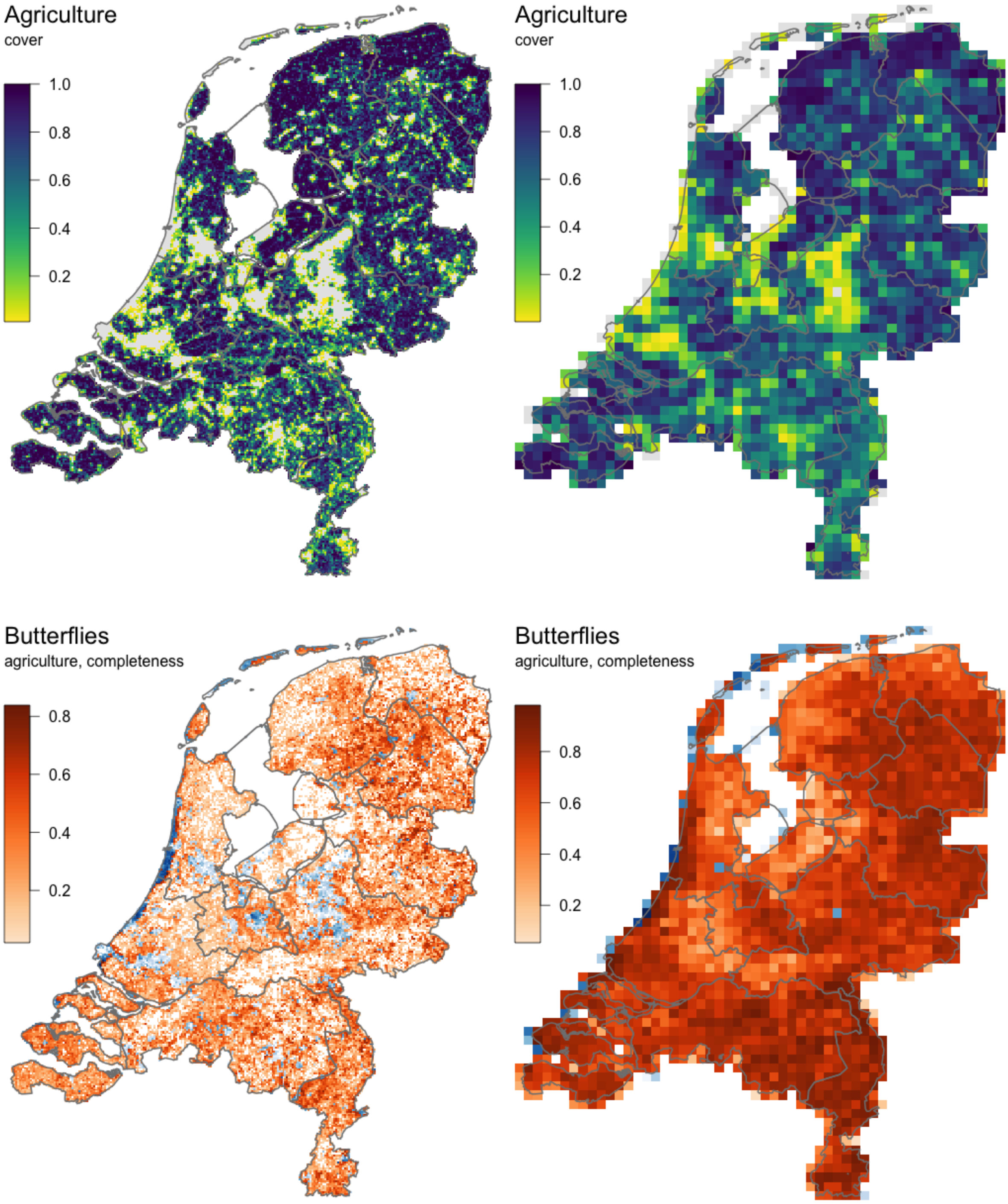

Figure 20. Idem, for agricultural areas.

Agriculture-specific butterfly species are among the most widespread butterfly species (see Table 13), so it's no surprise that species completeness is high throughout the country, even in regions which are densely forested (Veluwe) or urbanized (Amsterdam, Rotterdam). It's therefore more interesting to see where agricultural species completeness is relatively *low*. This is mainly in NE North-Holland, the Utrecht–South-Holland border area, de Betuwe region, the IJsselmeerpolders and NW Friesland. These are all regions with fairly intensive agriculture, i.e. few other land uses.

4.4.5 Habitat-specific species richness and landscape spatial structure

Using a generalized framework for ecosystem type diversity, fragmentation, and the spatial structure of landscapes (Section A generalized framework for ecosystem type diversity, fragmentation, and the spatial structure of landscapes.A.5), the spatial patterns in the species completeness can be linked to specific ecosystem pattern types. In this case the spatial transition probabilities of two ecosystem types A and B, which is the probability that pixels of type A and type B are adjacent to each other.

One example is the spatial pattern in forest butterfly species completeness. As mentioned before (Section 4.4.1) this map did not show a high completeness for the large forested areas such as the central Veluwe region. Instead, the forest-butterfly completeness map shows most agreement with the maps depicting the transition between forest and either agricultural grassland and cropland, suggesting that the forested edges of agricultural fields are the habitat of choice for these species. This furthermore suggests the value of a mosaic-type of landscape, such as found in the Twente region, from a biodiversity perspective.

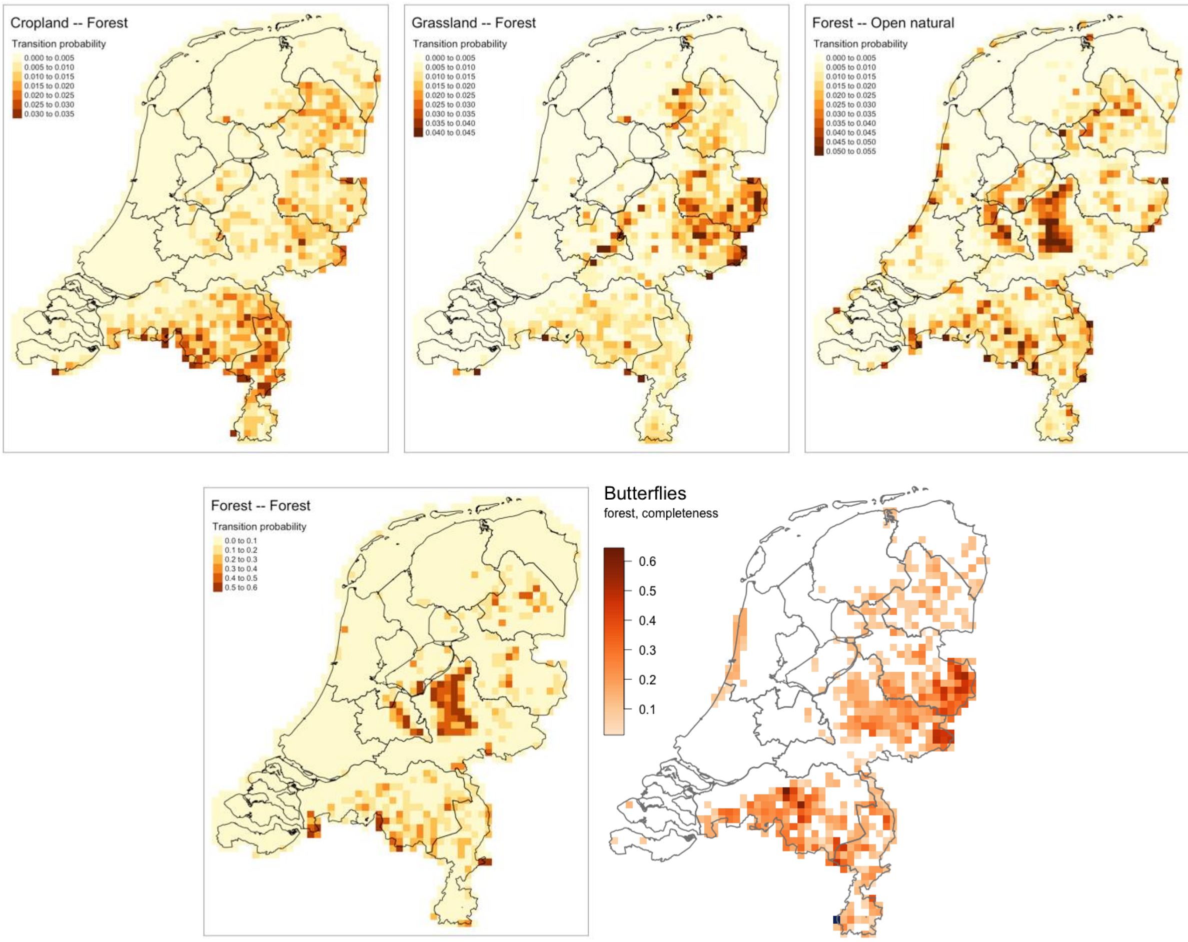

Figure 21. Top row, left: spatial transition probabilities for cropland vs forest (i.e. the probability forest and crop land pixels are adjacent). Middle: idem for (agricultural) grassland and forest. Right: idem for open natural ecosystems (heathland etc) and forest. Bottom row, left: idem for forest only (i..e., the porbability that two forest pixels are adjacent). Right: forest-specific butterfly species completeness (for reference; identical to Figure 17).

A second example is formed by the 'empty holes' in the agricultural butterfly completeness map (first presented in Section 4.4.4). Comparison with appropriate spatial transition maps suggests that these regions of decreased species completeness correlate with areas where agricultural grasslands are most homogenous, i.e. with very few other ecosystem types in the landscape mosaic. To a lesser extent this is also the case with homogenous cropland areas (Figure 22). These results are consistent with the those by Seibold et al. (2019), who, in their investigation of strongly declining trends in German insect and arthropod biomass, abundance, and species diversity, conclude that "[their] suggest that major drivers of arthropod decline act at larger spatial scales, and are (at least for grasslands) associated with agriculture at the landscape level".

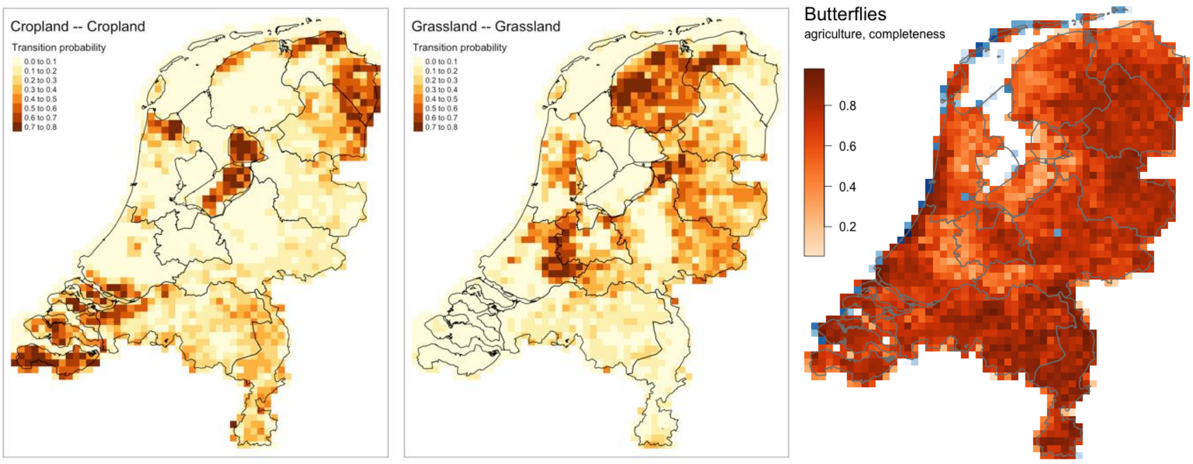

Figure 22. Left, middle: Spatial transition probabilities between cropland and itself and agricultural grassland, depicting areas of large homogenous agricultural landscapes. Right: agriculture-specific butterfly species completeness.

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Abbreviations used:

CBS: Statistics Netherlands (CBS), The Hague

PBL Netherlands Environmental Assessment Agency, The Hague

RIVM National Institute for Public Health and the Environment, Bilthoven

WUR Wageningen University and Research, Wageningen

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Appendix A Methodological details

A.1 Red List Indicator

The Red List length is defined as the number of threatened species on the list. This data is available for 1995 and 2005 (in which official Red Lists were established for all species groups) and from 2013 onwards (using virtual red lists if official updates were not available, using the same methodology for establishing the official Red Lists).

The Red List colour quantifies the accumulated threat by assigning a value of 1 to each “vulnerable” species, 2 to each “sensitive” species, etc., up to 4 to each “extinct” species, and summing up for all species groups. The Red List Colour indicator is obtained by using the first year, 1995, as a reference year, which is assigned an index value of 100.

A.2 Threatened species account

An account for threatened species for 2005–2015 was developed from the Red List status for both years. Six different status levels yields 36 possible transitions (e.g. *Vulnerable* in 2005; *Endangered* in 2013). Each of the 1771 species considered for the Red List Indicator (i.e., including common species that currently are not threatened at all) was mapped to one of these transition categories, yielding a total number of species per transition category (Figure 23).

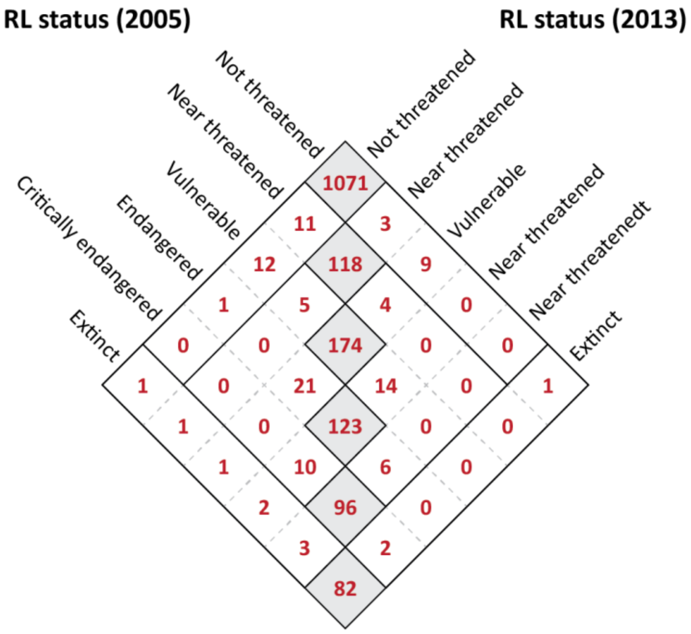


Figure 23. Red List transition matrix, showing the number of species changing from one RL category to another.

In a second step, these transition categories were mapped to six different mutation types, based on suggestions in the SEE-EEA handbook (Figure 24) It should be noted that conceptually these mutation classes are now mutually exclusive. For instance, if a species changes status from *Critically Endangered* to *Extinct*, it is both an “*increasing threat level*” as a “*local extinction*”. In this case, preference is given to “*local extinction*” to signal the more fundamental change in status. Similarly, change from *Not threatened* to Extinct is both a “*new addition to the [red] list*” and a “*local extinction*”. Again, preference is given to “*local extinction*”. For symmetry reasons a similar preference is given to “*Rediscoveries*”.

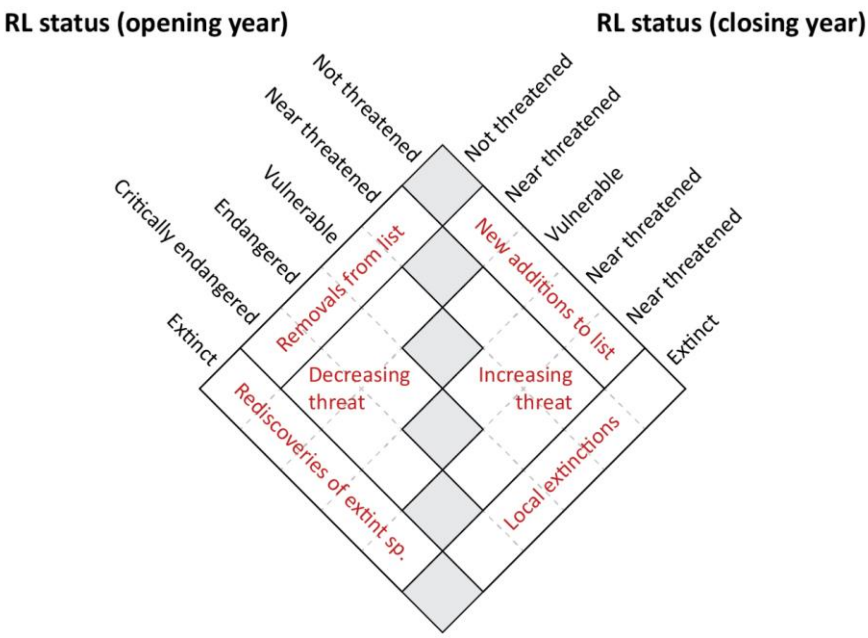


Figure 24. Conceptual diagram showing the mapping from Red List status changes to account mutation categories.

A.3 LPI trend and change analysis

Most biodiversity indicators show a strong interannual variation, that can be due to either chance or variability in covariates such as weather that are independent of drivers behind long-term changes in biodiversity such as changes in climate, land use, pollution, ground water levels etc. For accounting purposes usually a fixed period is considered, and the state at the beginning of this period ('opening stock') is compared to the state at the end of the period ('closing stock') and the changes during the period are unraveled in various types of additions (increases) and subtractions (decreases) of the stock variable. When small-scale fluctuations ('e.g. weather') are large compared to the long-term fluctuations ('climate'), chances are that the resulting accounting tables mainly account for these small-scale fluctuations (noise) rather than the longer-term fluctuations (signal) that we are interested in.

To increase the signal-to-noise ratio of change detection in biodiversity time series a smoothing technique is applied, which is based on Kalman filtering and is used extensively in environmental analysis in the Netherlands (Visser, 2004; Visser et al, 2018). This method operates as follows:

1. A structural time series model is iteratively fitted (forwards) to the raw annual time series.
2. A (fixed interval) smoother is constructed from the model and applied (backwards).

These two steps yield a times series of the smoothed variable and uncertainly information, based on the variance within the original data.

3. Smoothed variable S_1 and S_2 for time steps T_1 and T_2 are compared, taking the underlying uncertainty structure into account, to detect if S_1 and S_2 are significantly different from each other. The change between T_1 and T_2 thus is either *increasing*, *decreasing* or *stable*.

A.4 Occupancy based-distribution analysis

Information on changes in species distribution is widely used to document changes in biodiversity. The traditional way to compile this information is by means of well-designed monitoring schemes, using standardized field and postprocessing protocols. Increasingly, 'opportunistic' citizen science data becomes available. Often, however, this data is collected without standardized field protocol and without a design ensuring the geographical representativeness of the sampled sites, making the value of this data for species distribution and biodiversity purposes less clear. Occupancy models (MacKenzie et al., 2006) provide a way to deal with detection bias, and more general unknown and varying observation efforts (van Strien et al., 2013, and references therein).

Occupancy models distinguish between the probability that a species is present at a site (i.e., occupies the site), and the probability that it is detected. The occupancy model consists of two hierarchically coupled submodels, one for occupancy and one for detection, the latter being conditional on the occupancy submodel. The occupancy submodel takes both persistence and colonization probabilities into account. The detection submodel estimates probability of detection (per species, per site, per year), based on visit date and observational effort (using the length of the observation list as a proxy). See van Strien et al., (2013), and references therein, for full details.

Here, we use the results of occupancy modeling, applied by Arco van Strien of Statistics Netherlands, to analyze datasets of butterflies. These results are analyzed in terms of biodiversity, and its spatial components.

A.4.1 Probabilistic distribution extent.

The average spatial distribution extent for all butterfly species was determined by taking the mean occupancy probability for all 5km land grid cells. Because the occupancy probabilities range between 0 and 1, the uncertainty in occupancy is therefore translated to a decrease in extent (a probability of 0.5 is interpreted as an area of 0.5 grid cell. Thus, extent should be interpreted as an expected value, given the underlying uncertainties. The advantage of this method is that a gradual decrease in occupancy probability is reflected in a gradual decrease in distribution extent without the need to include uncertainty ranges in the extent indicator. The alternative would be to keep extent at the same level, but increase the uncertainty, which felt less appropriate.

A.4.2 Relative extent vs index method

Relative extent has been quantified using the maximum overall extent during the data period (1990–2017). That is, the number of 5km grid cells for which at least one year of occupancy probability >0 has been modelled. This approach deviates from the traditional index method where the value at the starting year is used as reference. Because for some species this value is extremely low to zero (*Euplagia quadripunctaria, Argynnis aglaja, Argynnis paphia, Leptidea sinapis*) this approach would not work.

A.4.3 Change vs trend

In this Biodiversity Account, the trends during the accounting period have been estimated using a method comparing the (smoothed) values at the first and last years of the period, i.e. the opening and closing stock. This 'net change' method is in contrast with the 'linear trend' estimation method normally applied for species abundance studies, e.g. the CLO.

For the butterfly distribution analysis both methods where applied, and only in five cases did they not agree. For *Lycaena tityrus* (Bruine vuurvlinder) the 'change' was *stable*, while the linear trend was *increasing*. Inspection of the time series (Figure 27) suggests that is likely cause by a quick (2 yr) decrease in extent, followed by a longer (5yr) and slower increase of similar magnitude. For the other 4 species, the change was either *increasing* (1x) or *decreasing* (3x), while the linear trend was *stable*. Inspection of the time series suggests that these are border cases between decreasing or increasing and stable, where a different mathematical method leads to a different conclusion (using the same threshold values). It should be noted that the change assessment is based on smoothed data from the whole time series, while the linear trend assessment is based on smoothed data for the specific time span only.

A.4.4 Aggregated overall extent trend.

The aggregated overall trend in butterfly distribution extent (Figure 14) is be constructed by taking the (unweighted) average of the time series for the individual species. Because all extents are expressed as relative extents the rare species weigh equally as the more common or abundant species, which is a favourable property from a conservation point of view.

A.4.5 Species richness

Species richness maps are obtained by combining (adding) occupancy probability maps for individual species. As with extent (Section A.4.1), the uncertainly associated with the occupancy probabilities translates into partial presence of a species within a grid cell during a specific year. Thus, an occupancy probability of 0.5 counts as half a species. Again, this approach was used to infer expected values for species rich based, given the occupancy uncertainties.

Changes in species richness during the accounting period were detected by first constructing annual maps of species richness, using the same probabilistic approach as described above (i.e. adding up occupation probabilities), followed by a smoothing of the time series per grid cell. The magnitude of change was determined by comparing the smoothed values of 2006 with 2013, taking uncertainties into account as described earlier. Magnitudes where the change was *stable* were reset to 0.

A.5 A generalized framework for ecosystem type diversity, fragmentation, and the spatial structure of landscapes.[6]

Current practice within the SEEA-EEA is to classify all basic statistical units (BSUs) according to an ecosystem typology. In the Netherlands, this is the Land Cover and Ecosystem Units (LCEU) map. Contiguous areas of a single ecosystem type form a single Ecosystem Asset, which are the units for ecosystem accounting. Accounting tables are used to organize information on ecosystem extent, condition, and services, aggregated by ecosystem type. Accounting tables thus typically list the extent of forests and grassland, the condition of forests and grassland, and the services provided by forests and grasslands.

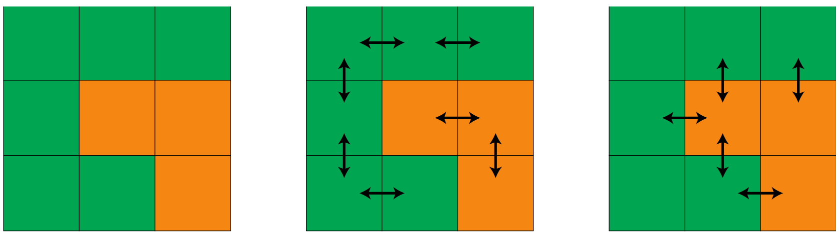
By organizing information in this way, the implicit assumption is that all forests are comparable, and that forests and grassland are independent of each other. In reality, however, this is not the case. For instance, the esthetic attractiveness of rural landscapes for recreation might be different for a region composed of large grassland areas, and a few large forests, compared to another region where small acres of grassland are intertwined by tiny forests, while the total coverage of forest and grassland might be the same. The difference between these two regions is the spatial structure of the landscape, and this aspect is currently ignored in many ecosystem accounts.

Many individual landscape composition and fragmentation metrics have been proposed in the literature, and used in biodiversity studies. For instance, Aguirre-Gutiérrez et al (2016, 2017) use the relative coverage of eight land cover (LC) types, and the number of LC types within 5x5 km areas, as metrics for landscape composition. Habitat fragmentation is assessed using two metrics: one for average area of suitable habitat patches (in m^2), and for total edge density (total length of the border between LC classes, in m/ha). The edge density is measured either considering all eight LC classes, or considering LC classes reclassified as being managed or unmanaged. Using this approach, landscape composition and fragmentation metrics are computed independently of each other, in a static way, not allowing for much further postprocessing to address specific land-cover issues.

Here, we present a more generic framework that encompasses all above metrics, allows for flexible postprocessing analysis, and is numerically easy to compute. The key of the method is that for larger landscape areas (e.g. 5x5 km grid cells) the spatial transition probabilities between LC classes are measured.

Figure 25 illustrates the principle for a simplified example using a 3x3 grid and 2 land cover classes, A end B. For the generic case of a $N \times N$ grid, there will be $N(N-1) = 6$ east–west cell-to-cell transitions, and $N(N-1) = 6$ north-south transitions, resulting in a total of $2N(N-1) = 12$ transitions for the 3x3 case. Of these, only 5 of these will be true LC transitions (i.e. from type A to type B, or vice versa. The remaining intercell edges are either connecting two type A cells (5 cases) or two type B cells (2 cases).

Eventually, we'll like to represent all transitions as probabilities, summing up to 1, and, for computational convenience, we like to store these probabilities in matrix form. For this, two options are available (see Figure 25): In the first option (Panel d) inter-class probabilities are stored twice (as e.g. A–B and B–A), and consequently the intraclass probabilities (e.g. A–A and B–B) are doubled to ensure the total probabilities to be 1. The second option (panel e) the interclass probabilities are stored only once, and the resulting matrix is in upper triangular form. For ease of use, the first option is used in the current work.



a) b) c)

Land cover classes
A
B

	A	B
A	10/24	5/24
B	5/24	4/24

d)

	A	B
A	5/12	5/12
B	0	2/12

e)

[6] This section is taken verbatim from Bogaart and de Jong (2018)

Figure 25. Simplified example using two LC classes and associated spatial transition probabilities, Upper panels show (a) the land cover map, (b) the intraclass spatial transitions, (c) the interclass transitions. Lower panels show two different approaches to ensure that total probabilities are 1: (d) by doubling the intraclass probabilities, or (e) recording the interclass probabilities only once.

A.5.1 Links to composition and fragmentation metrics

It can easily be shown how the various landscape composition and fragmentation can be derived from the spatial transition probability matrix (STPB).

- Fractional coverage is approximately equal to the row or column totals of the STPM.
- Number of LC classes is equal to the number of classes with a fractional coverage >0.
- Edge density is equivalent to the sum of the non-diagonal elements of the STPM.

A.5.2 Scaling

Many ecosystem type classification schemes are hierarchical in nature, e.g. by distinguishing by 'natural' and 'artificial' at the highest level, and then subdividing 'natural' in 'forest', 'open nature', 'wetlands' etc., and further subdividing 'forest' in 'deciduous forest', 'evergreen forest' and so on. Depending on the research or policy questions considered, one may be interested in a particular hierarchical level. For instance, for ecological applications one might want to cluster all build-up units and areas together, while for a more socio-economic applications one might to distinguish between the various use classes.

The STPM approach allows for a simple scaling between more fine-grained classification and a more coarse-grained classification, as long as the coarse-grained classification can be derived from clustering fine-grained classes. This is achieved by simply summing up the matrix elements from the fine-grained STPM that form a single coarse-grained STPM, see Figure 26 for an example.

	A	B_1	B_2
A	0.2	0.1	0.05
B_1	0.1	0.1	0.1
B_2	0.05	0.1	0.2

a)

	A	B_1	B_2
A	0.2	0.1	0.05
B_1	0.1	0.1	0.1
B_2	0.05	0.1	0.2

b)

	A	B
A	0.2	0.15
B	0.15	0.5

c)

Figure 26. Example for upscaling the spatial transition probability matrix from a fine-grained classification, where subclasses B1 and B2 are distinguished, to a coarse-grained classification, having only a single B class.

Two possible aggregations of LCEU map of the Netherlands are shown in Table 11.

Table 11. Reclassifications of the Land Cover and Ecosystem Units (LCEU) maps for the Netherlands. Indented LCEU types denote functional ('code 2') units that replace underlying physical ('code 2') units. River flood basis functional units are ignored here.

LCEU	Reclass #1	Reclass #2
Dunes with permanent vegetation	Forest etc	Natural
Deciduous forest	Forest etc	Natural
Coniferous forest	Forest etc	Natural
Mixed forest	Forest etc	Natural
Bushes and hedges bordering fields	Open natural	Natural
Active coastal dunes	Open natural	Natural
Beach	Open natural	Natural
Heath land	Open natural	Natural
Inland dunes	Open natural	Natural
Fresh water wetland	Open natural	Natural
(semi) Natural grassland	Open natural	Natural
Public green space	Open natural	Natural
Other unpaved terrain	Open natural	Natural
Salt marsh	Open natural	Natural
Non-perennial plants	Cropland	Agricultural
Perennial plants	Cropland	Agricultural
Meadows (grazing)	Grassland	Agricultural
Greenhouses	Build-up	Build-up
Farmyards and barns	Build-up	Build-up
Residential area	Build-up	Build-up
Industry: offices and businesses	Build-up	Build-up
Services: offices and businesses	Build-up	Build-up
Public administration: offices and businesses	Build-up	Build-up
Roads, parking lots, runways, other	Build-up	Build-up
Forestry: offices and businesses	Build-up	Build-up
Fishery: offices and businesses	Build-up	Build-up
Non-commercial services: offices and businesses	Build-up	Build-up
Sea	Water	Water
Lakes and ponds	Water	Water
Rivers and streams	Water	Water
River flood basin	*not used*	*not used*

Appendix B Supplementary information

Table 12. Mean occupancy of 50 butterfly species. Averaging is during the accounting period 2006–2013.

Butterfly species		Mean occupancy		Change	
Dutch name	**Scientific name**	**5x5km grid**	**1x1km grid**		
Klein koolwitje	*Pieris rapae*	97.7%	58.3%	-0.9%	=
Dagpauwoog	*Aglais io*	95.9%	37.4%	5.6%	+
Klein geaderd witje	*Pieris napi*	95.3%	44.6%	-1.2%	–
Kleine vos	*Aglais urticae*	95.3%	42.3%	-0.4%	=
Groot koolwitje	*Pieris brassicae*	94.7%	35.1%	0.1%	=
Bont zandoogje	*Pararge aegeria*	92.7%	42.0%	13.1%	+
Bruin zandoogje	*Maniola jurtina*	92.3%	42.6%	2.4%	+
Gehakkelde aurelia	*Polygonia c-album*	90.4%	30.0%	1.9%	=
Icarusblauwtje	*Polyommatus icarus*	89.7%	24.6%	2.7%	+
Kleine vuurvlinder	*Lycaena phlaeas*	89.2%	28.3%	-0.7%	=
Zwartsprietdikkopje	*Thymelicus lineola*	87.0%	29.2%	-8.9%	–
Boomblauwtje	*Celastrina argiolus*	84.4%	21.4%	2.4%	=
Citroenvlinder	*Gonepteryx rhamni*	84.1%	27.9%	7.3%	+
Oranjetipje	*Anthocharis cardamines*	83.1%	29.9%	6.8%	+
Landkaartje	*Araschnia levana*	78.9%	20.2%	9.6%	+
Hooibeestje	*Coenonympha pamphilus*	70.6%	15.3%	12.5%	+
Groot dikkopje	*Ochlodes sylvanus*	68.8%	21.8%	12.8%	+
Argusvlinder	*Lasiommata megera*	67.5%	14.8%	-15.0%	–
Koevinkje	*Aphantopus hyperantus*	57.9%	21.7%	5.8%	+
Koninginnenpage	*Papilio machaon*	52.4%	8.6%	-11.8%	=
Eikenpage	*Favonius quercus*	49.9%	8.7%	6.0%	=
Oranje zandoogje	*Pyronia tithonus*	48.6%	22.6%	-4.9%	–
Bruin blauwtje	*Aricia agestis*	38.1%	5.1%	12.8%	+
Groentje	*Callophrys rubi*	24.5%	4.1%	1.7%	=
Geelsprietdikkopje	*Thymelicus sylvestris*	22.1%	2.0%	-19.2%	–
Kleine parelmoervlinder	*Issoria lathonia*	18.5%	2.3%	-4.0%	=
Heivlinder	*Hipparchia semele*	17.8%	3.5%	-8.0%	–
Heideblauwtje	*Plebejus argus*	17.2%	2.6%	-3.3%	–
Bruine vuurvlinder	*Lycaena tityrus*	12.4%	2.0%	3.0%	=
Kleine ijsvogelvlinder	*Limenitis camilla*	8.5%	1.2%	7.0%	=
Grote weerschijnvlinder	*Apatura iris*	7.9%	0.6%	26.0%	+
Bont dikkopje	*Carterocephalus palaemon*	7.1%	1.3%	1.6%	=
Kommavlinder	*Hesperia comma*	6.1%	0.9%	-5.1%	–
Bruine eikenpage	*Satyrium ilicis*	4.2%	0.4%	-5.6%	=
Duinparelmoervlinder	*Argynnis niobe*	3.8%	0.8%	9.6%	+
Spaanse vlag	*Euplagia quadripunctaria*	3.5%	0.6%	24.8%	+
Gentiaanblauwtje	*Phengaris alcon*	3.3%	0.3%	-23.1%	–
Sleedoornpage	*Thecla betulae*	3.1%	0.3%	-19.0%	–
Zilveren maan	*Boloria selene*	2.8%	0.4%	-2.9%	=
Aardbeivlinder	*Pyrgus malvae*	2.8%	0.4%	-6.4%	–
Grote parelmoervlinder	*Argynnis aglaja*	2.4%	0.4%	3.4%	=
Bosparelmoervlinder	*Melitaea athalia*	1.5%	0.3%	-3.9%	=
Keizersmantel	*Argynnis paphia*	1.4%	0.1%	33.1%	+
Boswitje	*Leptidea sinapis*	1.0%	0.1%	8.7%	=
Grote vuurvlinder	*Lycaena dispar*	0.7%	0.2%	0.4%	=
Veldparelmoervlinder	*Melitaea cinxia*	0.5%	0.1%	1.9%	=
Veenhooibeestje	*Coenonympha tullia*	0.4%	0.1%	-0.4%	=
Veenbesparelmoervlinder	*Boloria aquilonaris*	0.4%	0.0%	-22.1%	–
Veenbesblauwtje	*Plebejus optilete*	0.2%	0.0%	-20.0%	–
Kleine heivlinder	*Hipparchia statilinus*	0.2%	0.0%	-11.9%	–

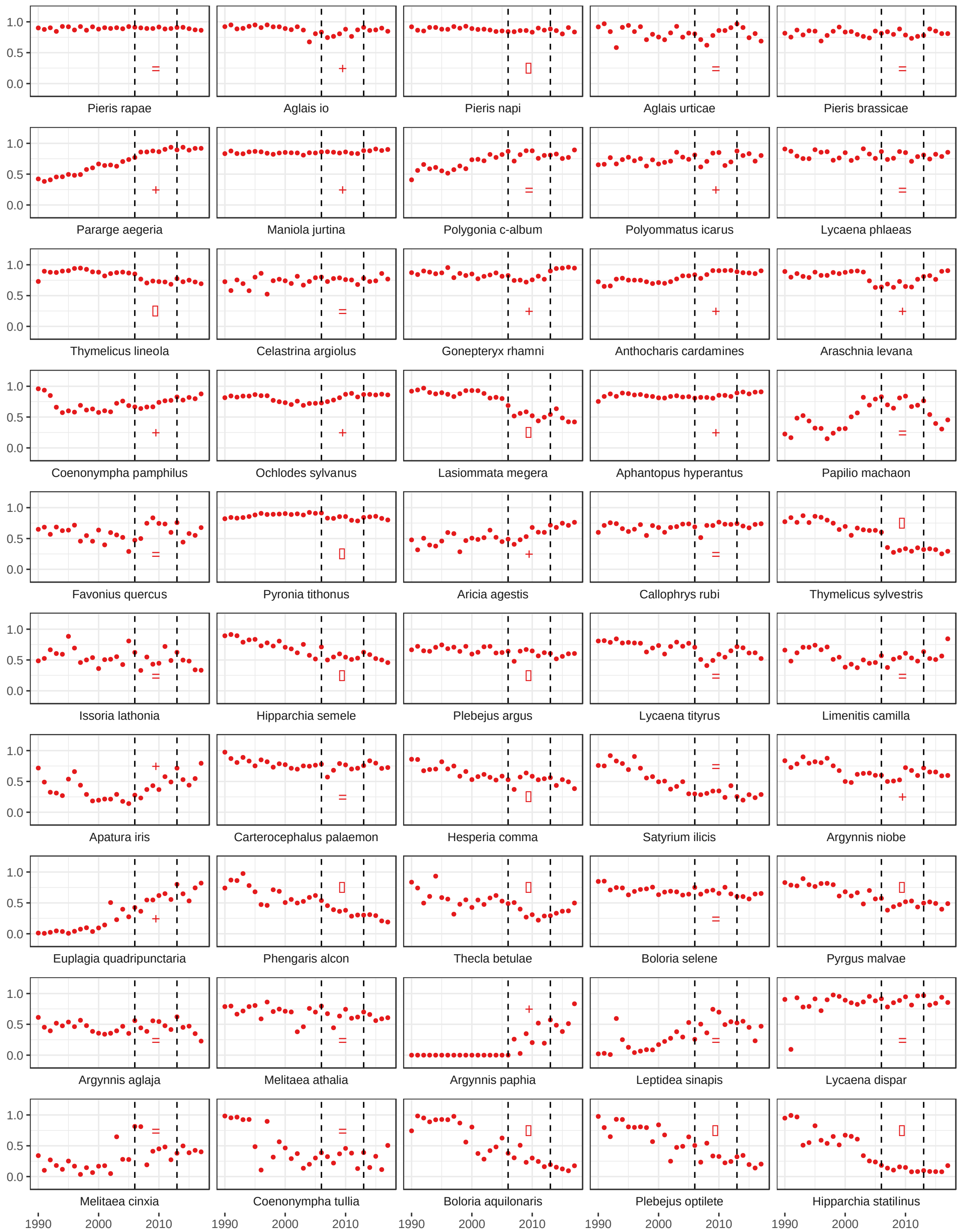


Figure 27. Trends in occupancy extent for 50 butterfly species, 1990–2017. occupancy extent is relative to the maximum extent for the species during the whole data period.

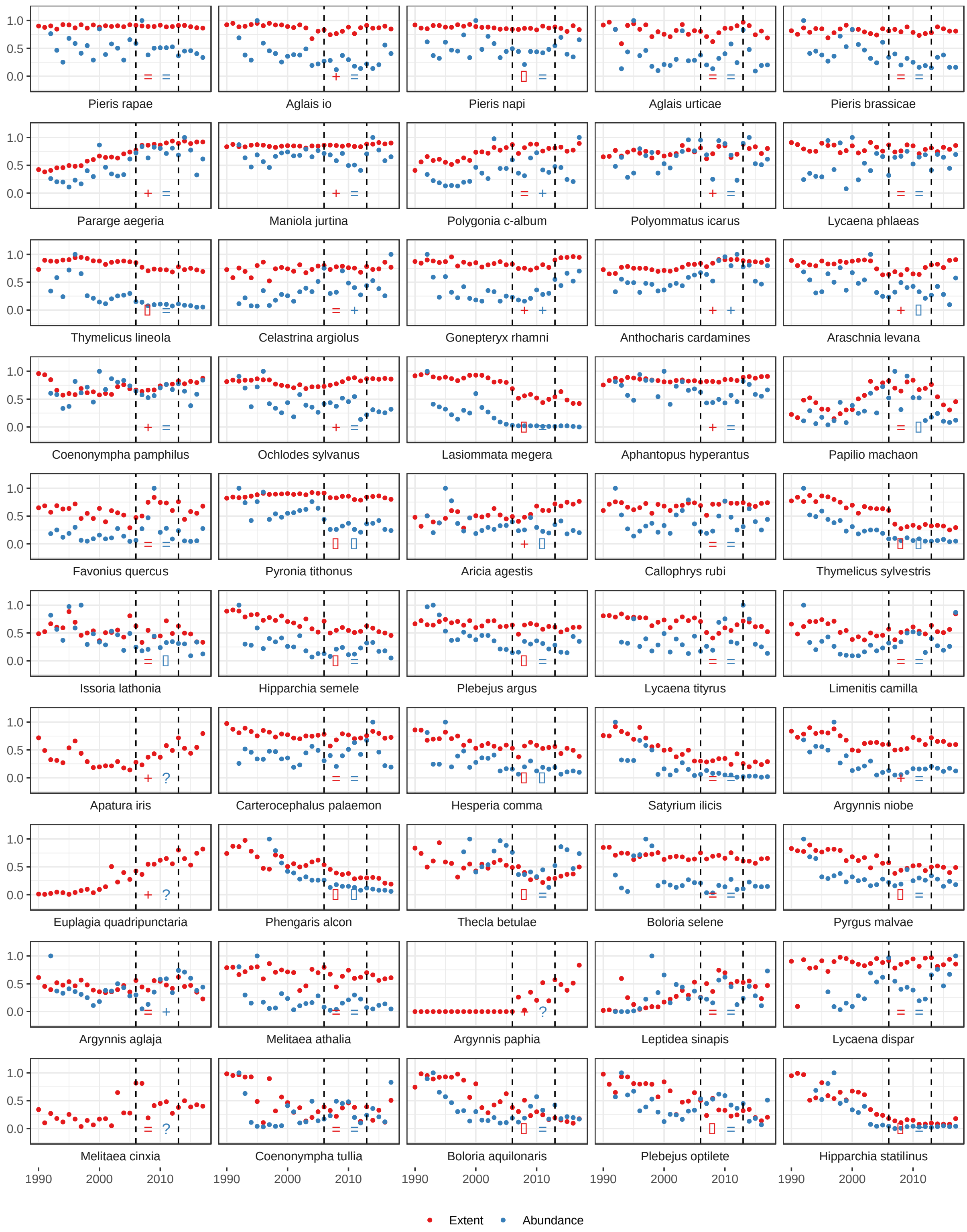


Figure 28. Trends in occupancy extent and LPI abundance for 50 butterfly species.

Table 13. Characteristic butterfly species for 5 different habitats. For reference, the same extent-based ordering as before has been used. Non-habitat-specific species are in gray.

Butterfly species		**Habitat**				
Dutch name	**Scientific name**	**Forest**	**Heathland**	**Dunes**	**Freshwater**	**Agricultural**
Klein koolwitje	*Pieris rapae*	·	·	·	·	·
Dagpauwoog	*Aglais io*	·	·	·	·	·
Klein geaderd witje	*Pieris napi*	·	·	·	·	✓
Kleine vos	*Aglais urticae*	·	·	·	·	·
Groot koolwitje	*Pieris brassicae*	·	·	·	·	·
Bont zandoogje	*Pararge aegeria*	·	·	·	·	·
Bruin zandoogje	*Maniola jurtina*	·	·	·	·	✓
Gehakkelde aurelia	*Polygonia c-album*	·	·	·	·	·
Icarusblauwtje	*Polyommatus icarus*	·	·	·	·	✓
Kleine vuurvlinder	*Lycaena phlaeas*	·	·	·	·	·
Zwartsprietdikkopje	*Thymelicus lineola*	·	·	·	·	✓
Boomblauwtje	*Celastrina argiolus*	·	·	·	·	·
Citroenvlinder	*Gonepteryx rhamni*	·	·	·	·	·
Oranjetipje	*Anthocharis cardamines*	·	·	·	·	✓
Landkaartje	*Araschnia levana*	·	·	·	·	·
Hooibeestje	*Coenonympha pamphilus*	·	·	·	·	✓
Groot dikkopje	*Ochlodes sylvanus*	·	·	·	·	✓
Argusvlinder	*Lasiommata megera*	·	·	·	·	✓
Koevinkje	*Aphantopus hyperantus*	·	·	·	·	✓
Koninginnenpage	*Papilio machaon*	·	·	·	·	·
Eikenpage	*Favonius quercus*	·	·	·	·	·
Oranje zandoogje	*Pyronia tithonus*	·	·	·	·	✓
Bruin blauwtje	*Aricia agestis*	·	·	·	·	✓
Groentje	*Callophrys rubi*	·	✓	✓	·	·
Geelsprietdikkopje	*Thymelicus sylvestris*	·	·	·	·	✓
Kleine parelmoervlinder	*Issoria lathonia*	·	·	·	·	✓
Heivlinder	*Hipparchia semele*	·	✓	✓	·	·
Heideblauwtje	*Plebejus argus*	·	✓	·	·	·
Bruine vuurvlinder	*Lycaena tityrus*	·	✓	·	·	·
Kleine ijsvogelvlinder	*Limenitis camilla*	✓	·	·	·	·
Grote weerschijnvlinder	*Apatura iris*	✓	·	·	·	·
Bont dikkopje	*Carterocephalus palaemon*	✓	·	·	·	·
Kommavlinder	*Hesperia comma*	·	✓	✓	·	·
Bruine eikenpage	*Satyrium ilicis*	✓	·	·	·	·
Duinparelmoervlinder	*Argynnis niobe*	·	✓	✓	·	·
Spaanse vlag	*Euplagia quadripunctaria*	·		·	·	·
Gentiaanblauwtje	*Phengaris alcon*	·	✓	·	·	·
Sleedoornpage	*Thecla betulae*	·	·	·	·	·
Zilveren maan	*Boloria selene*	·	·	·	·	·
Aardbeivlinder	*Pyrgus malvae*	·	✓	✓	·	·
Grote parelmoervlinder	*Argynnis aglaja*	·	✓	✓	·	·
Bosparelmoervlinder	*Melitaea athalia*	✓	·	·	·	·
Keizersmantel	*Argynnis paphia*	·	·	·	·	·
Boswitje	*Leptidea sinapis*	✓	·	·	·	·
Grote vuurvlinder	*Lycaena dispar*	·	·	·	✓	·
Veldparelmoervlinder	*Melitaea cinxia*	·	·	·	·	·
Veenhooibeestje	*Coenonympha tullia*	·	✓	·	·	·
Veenbesparelmoervlinder	*Boloria aquilonaris*	·	✓	·	·	·
Veenbesblauwtje	*Plebejus optilete*	·	✓	·	·	·
Kleine heivlinder	*Hipparchia statilinus*	·	✓	·	·	·
Total number of species		6	13	6	1	13