Detecting changes in essential ecosystem and biodiversity properties- towards a Biosphere Atmosphere Change Index: BACI

Deliverable 8.2: A pan-European assessment of the conservation status of Natura 2000 protected areas

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Responsible of the deliverable:	Signe Normand Phone: +4587154345 Email: signe.normand@bios.au.dk
Contributors:	Robert Buitenwerf[1], Brody Sandel[1], Jens-Christian Svenning[1], Signe Normand[1] [1] Aarhus University
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Aim

The aim of this deliverable is to assess the status of European protected areas with respect to changing ecosystem properties, as estimated from EO products.

Natura 2000 is the primary network of protected areas within the European Union (EU). In 2015, it consisted of 23,115 terrestrial reserves that together cover approximately 18% (794,368 km^2) of the EU land surface. There are large differences between sites in terms of reserve size, connectivity, protection status before the inception of Natura 2000 in 1992, implementation of management strategies, etc.

Rationale

Assessing the efficacy of such a large and diffuse network is an important but difficult task (Joppa et al. 2008, Ren et al. 2015). Various EU programmes have been designed around monitoring and assessing the efficacy of Natura 2000. The most recent of these is currently being performed under the Regulatory Fitness and Performance Programme[1] (REFIT) framework, aiming to deliver a "fitness check" on the birds and habitats directives. The birds and habitats directives form the legislative basis on which Natura 2000 is built.

The evaluation study[2] that supports the "fitness check" partitions the assessment into effectiveness, efficiency, relevance, coherence and added value of the directives. Our study is centred on the ecological aspects of Natura 2000 and is thus primarily concerned with effectiveness. In assessing the effectiveness of the directives, the "fitness check" relies heavily on dynamics in bird populations and land cover. These variables describe important changes in the state of the system, but do not necessarily reveal how or why changes occurred. Without understanding the functioning of ecosystems on a processes-level, this approach therefore provides little predictive power.

A strong focus on birds and habitats in assessing biodiversity can also result in additional challenges. For example, the lag period with which bird populations decline or increase in response to e.g. environmental change depends on species-specific life-history aspects such as fecundity, longevity and dispersal. Observations on population size and distribution alone may therefore hide important changes to underlying processes, such as demographic shifts. Similarly, monitoring the area of specific habitats can hide important changes to e.g. underlying vegetation dynamics. Habitats are discreet classes, while vegetation and biophysical conditions that determine a habitat class typically change gradually.

These potential pitfalls of current monitoring efforts illustrate the potential for metrics more closely aligned with the current state of a system. Ideally, such information could then feed into predictions of more derived variables, such as animal population dynamics and discreet habitat classes. Information on vegetation structure and functioning is well-suited for this purpose.

Vegetation structure is strongly related to biodiversity, partly because structurally more complex and heterogeneous vegetation and morphologically more diverse plant communities generate niche space that other organisms can occupy. Vegetation functioning also affects biodiversity, e.g. ecosystems with high primary productivity generate more litter, which is likely to support more diverse decomposer communities.

Despite the potential value of monitoring vegetation structure and functioning as indicators of biodiversity, such variables do not feature prominently in the EU's Streamlining Biodiversity

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[1] http://ec.europa.eu/environment/nature/legislation/fitness_check/docs/Mandate%20for%20Nature%20Legislation.pdf

[2] http://ec.europa.eu/environment/nature/legislation/fitness_check/docs/study_evaluation_support_fitness_check_nature_directives.pdf

Indicators[3] (SEBI) initiative, or other recent initiatives and reports such as the State of Nature in the EU[4] and Mapping and Assessment of Ecosystems and their Services[5] (MAES).

Earth observation (EO) satellites have provided proxies of vegetation structure and productivity since the early 1980's, although at relatively coarse spatial scales (5' ≈ 9 km). However, since 1999 continuous time series (8-16 day intervals) at much finer resolution (250-1000 m) have become available, enabling the monitoring of vegetation structure and functioning proxies for relatively homogenous areas of vegetation. Recently, conservation scientists have made a strong case for the value of remotely sensed ecosystem variables in biodiversity monitoring (Pereira et al. 2013, Skidmore et al. 2015, Pettorelli et al. 2016).

Earth observation variables that have been proposed as essential biodiversity variables include primary productivity, leaf area index (LAI) and vegetation phenology (Skidmore et al. 2015), which can be described using LAI or the normalised difference vegetation index (NDVI). The seasonal and inter-annual dynamics of these variables can serve as indicators for ecological processes such as natural vegetation succession, woody encroachment in grassy ecosystems and invasion by non-native species. However, none of the 1920 titles from key scientific studies[6] used in the EU's recent "fitness check" of biodiversity directives contain words referring to such EO variables and only two study titles contained the words "remote sensing".

In this study we therefore assessed the status of European protected areas with respect to changing ecosystem properties, as estimated from EO data. We followed a two-prong approach, the first of which is a study on historical changes in ecosystem properties. The second is a tool that allows the linking of biodiversity data (of birds) with proxies of vegetation structure as derived from Earth observation satellites. Specifically, we provide:

1. An in-depth pan-European analysis of temporal change in the vegetation structure as derived from EO-derived LAI.
2. A database in which, for each terrestrial Natura 2000 site, we merge essential biodiversity variables on birds with EO-derived LAI.

The aims, methods and results of each approach are described in the following sections.

European vegetation change

Aim

In recent decades human-induced global change has significantly altered ecosystem functioning around the world. Indicators of ecosystem functioning such as primary productivity (Nemani et al. 2003, Poulter et al. 2014), leaf phenology (Menzel et al. 2006, Buitenwerf et al. 2015) and vegetation "greenness" (Jong et al. 2012, Zhu et al. 2016) have all changed dramatically, with potentially severe consequences. For example, vegetation regulates the exchange of energy, carbon and water vapour between the land surface and the atmosphere, with important impacts on the global energy budget and thus global climates (Bonan 2008). Vegetation change may have adverse consequences for biodiversity, as vegetation shapes the available niche space for nearly all terrestrial organisms and dictates biotic interactions.

The majority of studies on large-scale changes in vegetation functioning are based on satellite data reaching back to the early 1980's, when the first sensors with consistent global coverage were launched.

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[3] http://biodiversity.europa.eu/topics/sebi-indicators
[4] http://www.eea.europa.eu/publications/state-of-nature-in-the-eu
[5] http://biodiversity.europa.eu/maes
[6] http://ec.europa.eu/environment/nature/legislation/fitness_check/docs/List%20Key%20documents.pdf

Although analyses of early satellite data have revealed large increases in the activity and productivity of European vegetation (Julien et al. 2006, Garonna et al. 2014, Mao et al. 2016, Zhu et al. 2016), the relatively coarse resolution of the data has hampered process-based understanding. For example, in Europe the coarse data has prevented tracking vegetation dynamics within individual land-cover or vegetation types, as humans have transformed the landscape into a mosaic of land covers at spatial scales that are often smaller than the spatial resolution of the longest satellite records.

The inability to resolve vegetation change within broad vegetation types is problematic because the links between ecosystem properties (e.g. biodiversity) and processes (e.g. productivity) are highly specific to vegetation types. For example, increased leaf area might represent natural growth in a forest, but might indicate undesirable shrub encroachment in a grassland. Being able to interpret vegetation dynamics in an ecological context is essential for validating process-based vegetation models, but also for assessing potential biodiversity consequences of vegetation change. The ecological context of vegetation change is also important when seeking continuous measures of land cover change.

In several parts of Europe a trend toward increased woodiness has been observed during recent decades. In some areas woody increases have been attributed to natural succession following farmland abandonment (Navarro and Pereira 2012, Schnitzler 2014, Ceausu et al. 2015, Skaloš et al. 2015, Kuemmerle et al. 2016). In other areas changing farming practices, generally associated with reduced grazing pressure, promote woody regrowth in both agricultural land (Gellrich et al. 2007) and semi-natural Natura 2000 areas (Timmermann et al. 2015). In this study we aim to assess historical change in the structure of semi-natural vegetation across Europe, with a particular focus on woody regrowth, as a means to assess the efficacy of the Natura 2000 network. By relating vegetation change to environmental and socio-economic drivers we address potential impacts of projected climate change on Natura 2000 vegetation and thus biodiversity (Hickler et al. 2012).

To quantify vegetation change we use LAI, which integrates information on vegetation structure and productivity, both of which strongly affect biodiversity. Moreover, LAI seasonality can be used to track changes in the seasonal dynamics of vegetation activity, which also affects biodiversity. For example, in Europe climate-induced changes in leaf phenology (Menzel 2013) affect migration and population dynamics of birds and animals, with consequences for fitness (Both and Visser 2001, Yang and Rudolf 2010).

To estimate the magnitude of woody regrowth within the Natura 2000 network we first ask if detected LAI increases occur within the Natura 2000 network, or whether its management buffers these increases. Since biodiversity of forest taxa generally increases with forest age, we therefore expect that the management of Natura 2000 forests should increase LAI more than in unprotected forests. If the conservation value of low-biomass vegetation such as grasslands and heaths lies in these areas remaining free from dense woody vegetation, LAI should remain constant, or at least increase less rapidly, in Natura 2000 compared to areas outside Natura 2000. Secondly, we ask if the restrictions that Natura 2000 protection places on land-use results in more gradual vegetation dynamics compared to unprotected areas, where land-use change is expected to be more dynamic. Since coarse-resolution LAI increases have been attributed to human-induced climate change, we lastly ask how LAI dynamics within major vegetation types vary across temperature and moisture gradients.

Methods

Leaf area index (LAI)

To quantify vegetation dynamics we used LAI derived from the MODIS sensor on NASA's Terra satellite. LAI for broadleaved vegetation can be interpreted as the one-sided leaf area (m^2) per ground area (m^2) and as half the total leaf area per ground area for needle-leaved vegetation (Myneni et al. 2015). LAI therefore contains information on both the structure of vegetation (e.g. broadleaved vs conifer forest) and productivity (e.g. dense vs sparse canopies). The LAI product is provided as 8-day composite images at 500 m resolution (Myneni et al. 2015). Quality assessments for each pixel allow further sub-setting and masking of poor quality data.

Natura 2000

Natura 2000 is the primary network of protected areas within the European Union. In 2015 it consisted of 23,115 terrestrial reserves that together cover approximately 18% (794,368 km^2) of the EU land surface. Within the network large differences between sites exist in terms of reserve size, connectivity, protection status before the inception of Natura 2000 in 1992, implementation of management strategies, etc. The boundaries of Natura 2000 protected areas for 2015 were extracted from a digital map by the European Environment Agency[7].

Land cover

In order to delineate areas that are not intensively used by humans we used the 2006 version of the CORINE land cover product to select 9 classes of “natural” and “semi-natural” land cover types. These land cover types will henceforth be referred to as semi-natural vegetation, recognizing that nearly all such areas have been influenced by human activities to some degree. Land cover types and details of area are given in Table 1. The CORINE land cover map was downloaded[8] as a grid with a cell size of 100×100 m.

Environmental data

To quantify LAI change along environmental gradients we selected monthly mean temperatures (Hijmans et al. 2005) and monthly mean soil moisture content (Trabucco and Zomer 2010), both of which impose fundamental constraints on plant functioning. These variables are not independent (Pearson’s ρ=0.66) as soil moisture depends on evapotranspiration, which in turn depends on temperature. However, since temperature not only affects plant functioning through water relations, but also directly affects physiological (e.g. photosynthetic rate) and behavioural (e.g. leaf expansion) processes, there is a need to interpret both variables separately and interactively. Data for all variables are long-term averages over 1960-1990 and were extracted from global grids with a resolution of 30”.

Data harmonisation

For every 500 m LAI cell we determined the cover of selected semi-natural vegetation types and discarded cells with <80% semi-natural vegetation cover, in order to exclude highly transformed land from the analysis. For each of the remaining 500 m LAI cells we determined the area under Natura 2000 protection and excluded cells with <80% Natura 2000 cover from the change analysis. Environmental data were re-projected and resampled to the 500 m LAI grid. These operations yielded a dataset with 1534477 Natura 2000 pixels and 4074014 pixels outside Natura 2000. All spatial operations were performed using the *raster* package (Hijmans 2016) in R (R Core Team 2016).

Change analysis

To quantify the magnitude of LAI change we calculated annual means from 2001 to 2015 on the full dataset. Previous studies have typically quantified LAI over a pre-defined growing season, thus focussing on growing-season productivity. However, by using LAI means over the entire year we also allow temporal shifts in the annual growing cycle to affect our measure of ecosystem functioning, e.g. because leaves emerge earlier in spring due to warming (Menzel et al. 2006) or canopies remain greener in autumn due to shifts in community composition (Fridley 2012). Moreover, aggregating reflectance-based time-series to annual values results in more reliable estimates of change (Forkel et al. 2013). We quantified changes in annual LAI using the Theil-Sen estimator, which is a robust non-parametric

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[7] http://www.eea.europa.eu/data-and-maps/data/natura-7

[8] http://www.eea.europa.eu/data-and-maps/data/clc-2006-raster-4

estimator of linear slope. Preliminary testing showed that for this data Theil-Sen slopes were near-identical to alternative robust measure of change as described in Buitenwerf et al. (2015).

To restrict comparison of LAI change between areas in and outside of the Natura 2000 network to cells with similar ecological, environmental and biogeographic processes, we paired inside and outside pixels. For each pixel inside Natura 2000 we identified the outside pixel that was environmentally most similar within a 50 km radius (similar biogeographic processes) and within the same vegetation type (similar ecological processes). Environmental similarity between pixels within this subset was defined as the minimum Euclidean distance in multi-dimensional environmental space, which consisted of scaled monthly mean temperatures and soil moisture.

Results

LAI increased in 84% of pixels with natural or semi-natural vegetation across Europe (Figure 1). The largest increases were detected in Eastern Europe, particularly in Poland, the Czech Republic, Slovakia and Romania. The most notable decreases were detected in the Landes forest of south-western France, the Ardennes region of Belgium, the British Isles and in parts of northern Scandinavia. More moderate decreases were detected in the southern Alps and south-western Sweden.

Absolute LAI increases were strongest in high-biomass vegetation types (i.e. woody vegetation), while increase in low-biomass vegetation was less pronounced, but still positive for the majority of pixels (Figure 2a). However, change expressed relative to the mean LAI in a location (pixel) shows that the greatest proportional LAI increases occur in vegetation types of intermediate biomass, which consist of partly woody vegetation (Figure 2b).

Differences between semi-natural areas in and outside of the Natura 2000 network were small relative to within-vegetation type variance, both in absolute and proportional units of change (Figure 2). For example, LAI tended to increase more inside Natura 2000 forests and grassland compared to outside forests and grasslands. In contrast, partly wooded vegetation types (transitional woodland-shrub and sclerophyllous vegetation) had, on average, greater LAI increases outside Natura 2000.

To control for the variation in LAI as a result of spatial structure (Figure 1), vegetation type (Figure 2) and environment we compared each pixel inside Natura 2000 to its closest outside analogue. The difference in LAI increase between inside pixels and their outside analogues was minimal (unimodal distribution with mean = -0.0007 and sd = 0.0087.

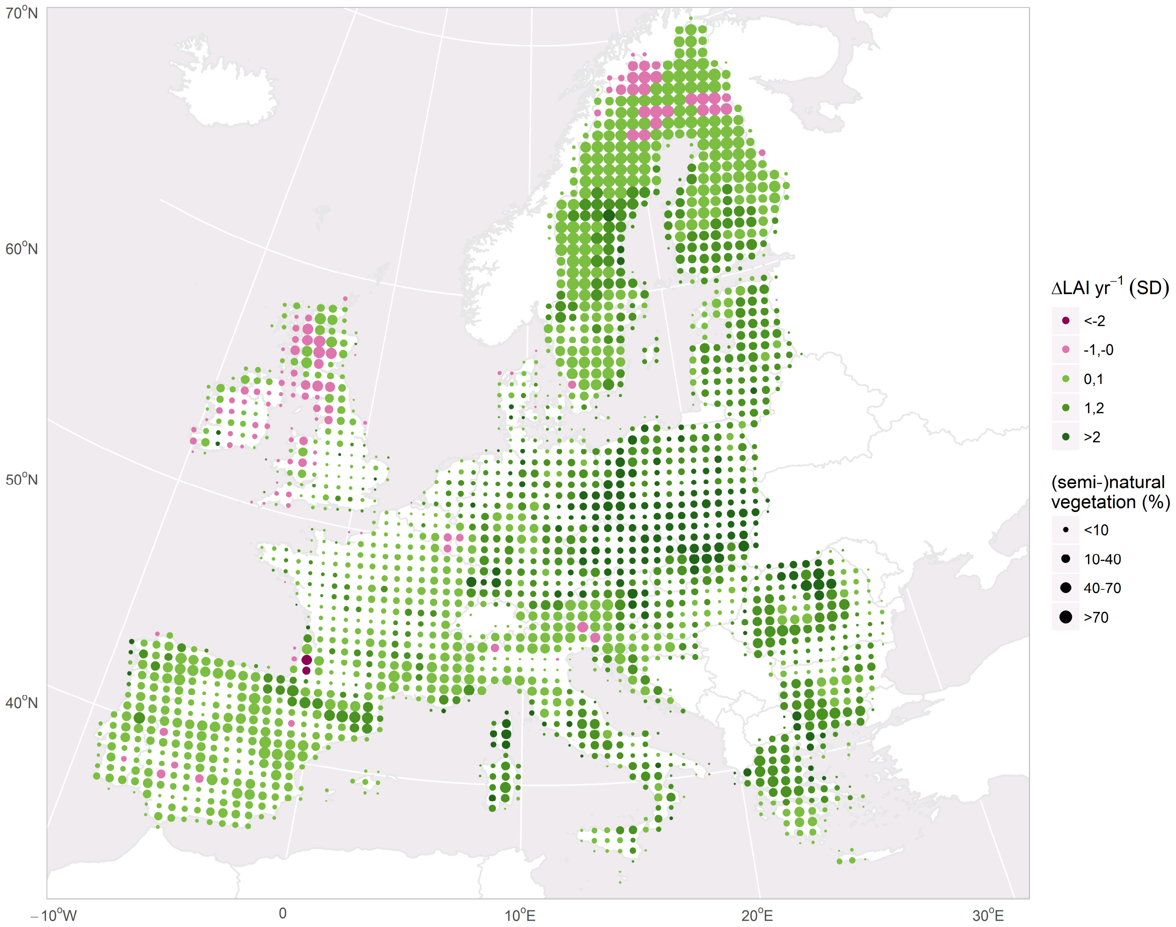

Figure 1 Change in the structure of semi-natural vegetation of Europe. Change was quantified using the Theil-Sen estimator of annual LAI means from 2001 to 2015. Colour breaks are placed at multiples of the ΔLAI standard deviation.

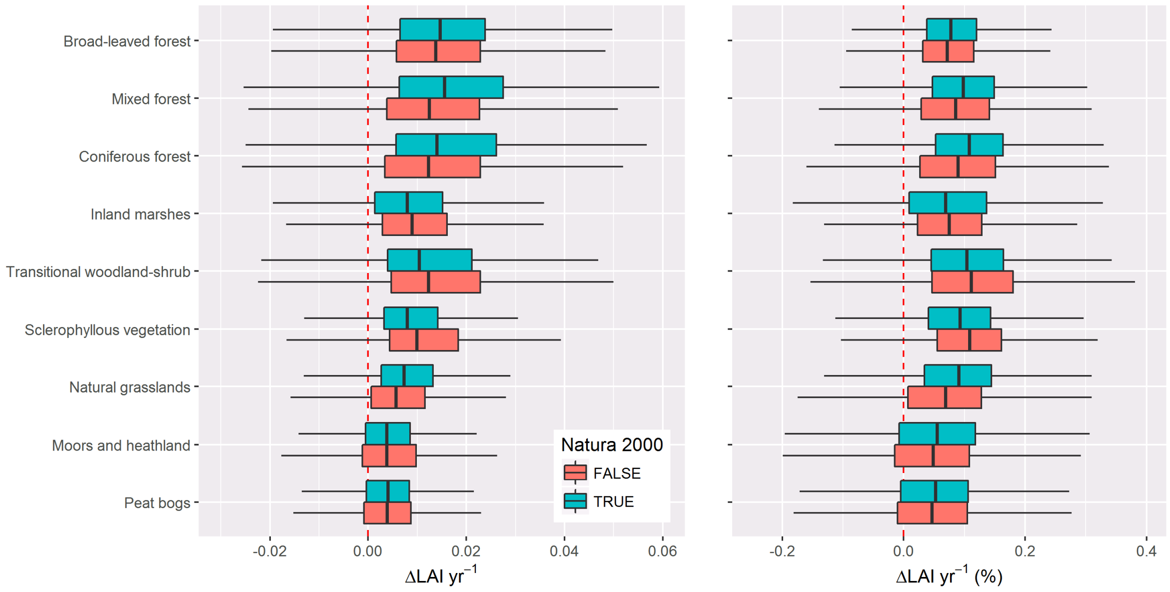

Figure 2 Annual LAI change in semi-natural vegetation types of Europe in absolute units (a) and relative to the mean LAI (b). Vegetation types are ordered by increasing mean annual LAI (a proxy for biomass) from bottom to top. Vegetation change was quantified using the Theil-Sen estimator of annual LAI means from 2001 to 2015. Vegetation types were taken from the 2006 CORINE land cover map. Within each vegetation type, change is shown for pixels inside and outside the Natura 2000 network.

Discussion

In this study we assessed vegetation change in Europe using EO-derived LAI and detect “greening” on 84% of land covered by semi-natural vegetation between 2000 and 2016. We demonstrate the links to ecological, biogeographic and socio-economic patterns and processes on vegetation change.

It is difficult to attribute LAI change to individual drivers without appropriate mechanistic models that describe the biological, environmental, biogeographic and anthropogenic processes from which LAI emerges. Moreover, the relatively short 15-year time-series hampers statistical attribution of LAI change to slow processes such as climatic or atmospheric change. Despite these impediments in attributing LAI change, several lines of evidence suggest that LAI increases did not simply result from natural (inter-annual) fluctuations in the weather, even though both temperature and rainfall are important drivers of vegetation productivity in this region (Ciais et al. 2005). Studies have consistently shown “greening” trends in Europe since the early 1980’s, when EO-satellites first permitted the regular monitoring of Earth’s entire surface (Jong et al. 2011, Mao et al. 2016, Zhu et al. 2016). Because “greening” has been detected with various satellite-based sensors and data products, these long-term trends in vegetation functioning are considered robust. The trends are consistent with predictions from Earth system models (ESMs), which represent the current understanding of processes that drive vegetation functioning, but only when anthropogenic effects on climate forcing and atmospheric composition are included (Mao et al. 2016, Zhu et al. 2016). This context of long-term anthropogenically driven “greening” supports the premise that the 2001-2015 LAI increases detected in our study form part of an ongoing upward trend. Another indication that weather fluctuations cannot be solely responsible for the detected vegetation change is that socio-economically driven shifts in land-use have favoured the expansion of woody vegetation in various parts of Europe during recent decades (MacDonald et al. 2000, Fuchs et al. 2012, Navarro and Pereira 2012).

The spatial signature of LAI increase strongly reflects the legacy of abandoned agricultural land, which has been particularly prevalent in Eastern Europe and mountainous regions of southern and central Europe (Figures 1 and S1). Land-use dynamics are a complex interplay of spatial and temporal processes, but a few key socio-economic and political developments can account for an important part of the spatial signature in LAI change. The dissolution of the Soviet Union in 1991 ended large-scale government-planned and subsidised agriculture across Eastern Europe, resulting in widespread abandonment of cropland (Kuemmerle et al. 2008, Estel et al. 2015, Skaloš et al. 2015). Simultaneously, the early 1990's saw reforms to the EU's Common Agricultural Policy, which was designed to implement agricultural subsidies. Measures to counter overproduction and adapt to increasingly free markets forced less profitable areas out of cultivation, particularly affecting regions of Portugal, Spain and Italy (Fuchs et al. 2012, Regos et al. 2016). Upon abandonment, successional turnover results in increasingly woody plant communities as forest is the "climax" vegetation state in most temperate regions without frequent disturbance from e.g. diverse populations of wild large herbivores. The detection of large LAI increases in Eastern and southern Europe are therefore consistent with natural succession on abandoned agricultural land.

There were few areas were ΔLAI was predominantly negative. One such "browning" hotspot was the Landes forest in south-western France (Figure 1), where the 2009 storm Klaus caused major windthrow in the planted maritime pine (*Pinus pinaster*) forests that dominate this region (Mora et al. 2014). LAI decreases in the UK cannot be easily explained by such an episodic disturbance since the majority of semi-natural vegetation consists of moors, heaths and grassland. Compared to mainland Europe, the UK has large populations of deer (Gill and Morgan 2010, Putman et al. 2011) and sheep (Eurostat), suggesting that intense grazing and browsing pressure in open vegetation types may be responsible for the anomalous LAI decreases in the UK. Herbivore suppression of woody growth in woody vegetation (Churski et al. 2016) may contribute to observed LAI declines in the UK, but also in northern Scandinavia, where intense reindeer grazing has been shown to reduce shrub cover (Herder et al. 2008, Cohen et al. 2013). Northern Scandinavia has also been subjected to outbreaks of geometrid moths, which defoliate large areas of birch forest (Jepsen et al. 2009). Geometrid moth outbreaks may be related to climate change (Hagen et al. 2007, Young et al. 2014).

Against expectations, the magnitude of LAI change in Natura 2000 protected areas did not differ consistently from unprotected areas (Figure 2). This suggests that management implemented under Natura 2000 directives has not generally generated measurable differences in vegetation state over the study period. Management goals and the level of implementation are known to vary widely among Natura 2000 sites, with some sites being managed primarily to protect rare bird or plant species and others more generally to maintain or increase biodiversity (European Union 2015). This variability in the mode and intensity of human impact may prevent a uniform response signal in a complex variable such as LAI.

Although direct links to e.g. the distribution and population dynamics of individual species are difficult to make without more detailed ground-based data, our findings generate some useful question and hypotheses for future studies. For example, partially wooded vegetation types had the largest proportional increases in LAI (Figure 2b). These increases were smaller in Natura 2000 areas than in unprotected areas, suggesting lower rates of woody expansion under Natura 2000 management. However, it has been argued that woody expansion may be favourable for overall biodiversity (Navarro and Pereira 2012). Forests, especially old-growth forests, are important reservoirs of biodiversity in Europe because they engineer structurally complex habitat and support a large number of species that are associated with dead wood. However, a large proportion of European biodiversity depends on open and semi-open habitats and would thus be threatened by uniform succession towards dense woody habitats. This includes species that require both forest and open vegetation, such as woodland butterflies that are declining due to loss of forest glades (Freese et al. 2006, Swaay et al. 2006). The general woody regrowth is clearly linked to fundamental societal changes driven abandonment of extensive traditional agricultural land use and in part overall land abandonment, and it seems unrealistic to reinstate such practices across large areas. A more tractable solution is to promote restoration of diverse assemblages of wild large herbivores, via facilitating spontaneous recolonization and via reintroduction (trophic rewilding: Svenning et al. (2016)), as these in past have been able to main substantial open and semi-open vegetation in European temperate landscapes (Wieren 1995, Svenning 2002, Sandom et al. 2014).

The findings of this study will be disseminated in the form of an open-access peer-reviewed article and in the BACI newsletter.

Natura 2000 database

Aim

The aim of this product was to deliver a database that can be used to directly asses the relationships between biodiversity metrics and a large number of climate, atmosphere and ecosystem variables. The information is provided at the level of individual Natura 2000 sites. These sites vary considerably in size, but they constitute the fundamental units around which management plans are designed and implemented.

The biodiversity metrics in this database focus on birds for several reasons. First, the Natura 2000 network has its roots in a 1979 EU directive on the protection of wild birds. Sites protected under this directive were later incorporated into Natura 2000. Second, data on the distribution and abundance of European wild bird species is of high quality and freely available through volunteer observer networks. Third, bird community dynamics serve as indicators of general ecosystem state.

Methods

Bird data

Bird observations were from eBird[9] (Sullivan et al. 2009), which is an online platform used by many amateur bird-watchers across Europe to list and track sightings. In total, we obtained nearly 1.3 million individual observations across 851 species and corresponding with 65818 observation events (a unique latitude × longitude × date combination).

Bird species were then classified according to their commonness and habitat preferences. Species of conservation concern were termed "Threatened", and included species categorized as Near Threatened, Vulnerable, Endangered and Critically Endangered by BirdLife's European Red List of Birds[10]. We assigned species as forest or farmland specialists (or neither), using the same classification as the European Bird Census Council's Trends of Common Birds in Europe[11]. Finally, birds on this list (148 species, comprising 68.3% of the total bird observations) were considered "common". For each observation event, we calculated species richness and the proportions of individuals from species classified as Threatened, Common, Farmland specialists, and Forest specialists. We also used Chao's (1984) estimator of species richness based on abundance data to correct the richness estimate for incomplete data.

To describe bird community status and trends in Natura 2000 sites[12], we then retained only observation events with at least 100 individual birds and at least 5 species observed, in order to remove casual observations that may give very skewed impressions of community composition. In total, 48040 observation events met these criteria, of which 12955 were located within Natura 2000 sites. These observation events form the basis of the database. They extend back as early as 1981, but more than 91% of the observation events occurred since 2000.

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[9] http://ebird.org

[10] http://www.birdlife.org/europe-and-central-asia/european-red-list-birds-0

[11] http://www.ebcc.info/index.php?ID=485

[12] http://www.eea.europa.eu/data-and-maps/data/natura-7

Within each Natura 2000 site, we then calculated the mean of the proportions of Threatened species, Common species, Farmland specialists and Forest specialists across all observations within that site. If the site had at least two events from different years, we also calculated the trend in these proportions as the correlation between year and the proportion value.

While these estimates are potentially highly valuable for their fine geographic resolution and broad spatial extent, it is important to recognize their limitations. Most importantly, eBird data is not the result of an organized sampling design, and is therefore highly unbalanced and biased. Observers may target particular habitats (for example, avoiding farmlands), may not record all birds observed during a visit (for example, may ignore common species) and make errors in identification. Nevertheless, fine-grain monitoring using eBird data has been shown to perform well compared to organized field surveys, at least in one case (Callaghan and Gawlik 2015). We especially urge caution in interpreting results from any one or small set of Natura 2000 sites, as these may reflect only a few observations of birds through time.

LAI data

Information on vegetation structure was represented by the LAI, which is defined as the one-sided leaf area per ground area (m^2 m^{-2}) in broadleaved vegetation and as half the total leaf area per ground area for needle-leaved vegetation. This data was obtained from the Moderate-resolution imaging spectro-radiometer (MODIS product MOD15AH2 version 6[13]). The data has a spatial resolution of 500m and a temporal resolution of 8 days. Annual means were calculated from the 8-day values for the years 2001-2015.

Land Cover

We used the 2006 version of the CORINE land cover product[14] to construct land cover classes that are aligned with the delineation of bird species into functional types. We combined land cover classes to calculate, for each Natura 2000 site with bird diversity data, the proportion of agricultural, forest, open vegetation (grassland + heaths), shrubland, wetland and water. We also calculated the proportion covered by semi-natural land cover classes, which were used in our analysis of historical LAI change in Europe.

Human influence

Data on human influence were taken from Esty et al. (2005).

Analyses

To explore the potential of this database to support conclusions about conservation status, we performed some simple exploratory analyses. In addition to site-level characteristics, we also included national statistics, including a range of environmental indicators (Esty et al. 2005). We then fit random forest models to explain status and trends of different bird groups from LAI mean and trends, the human influence index and these indicators. Examples of the response curves fit by these models are shown below. One country-level indicator that was consistently associated with bird status was the Total Fertility Rate, a measure of population stress (Esty et al. 2005).

Results

All variables included in the database are listed in Table 1 with a brief description and the data source.

Figure 3 shows the results of some exploratory random forest models in which the proportion of threatened bird species was explained by vegetation structure, human influence index and human fertility rates.

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[13] https://lpdaac.usgs.gov

[14] http://www.eea.europa.eu/data-and-maps/data/clc-2006-raster-4

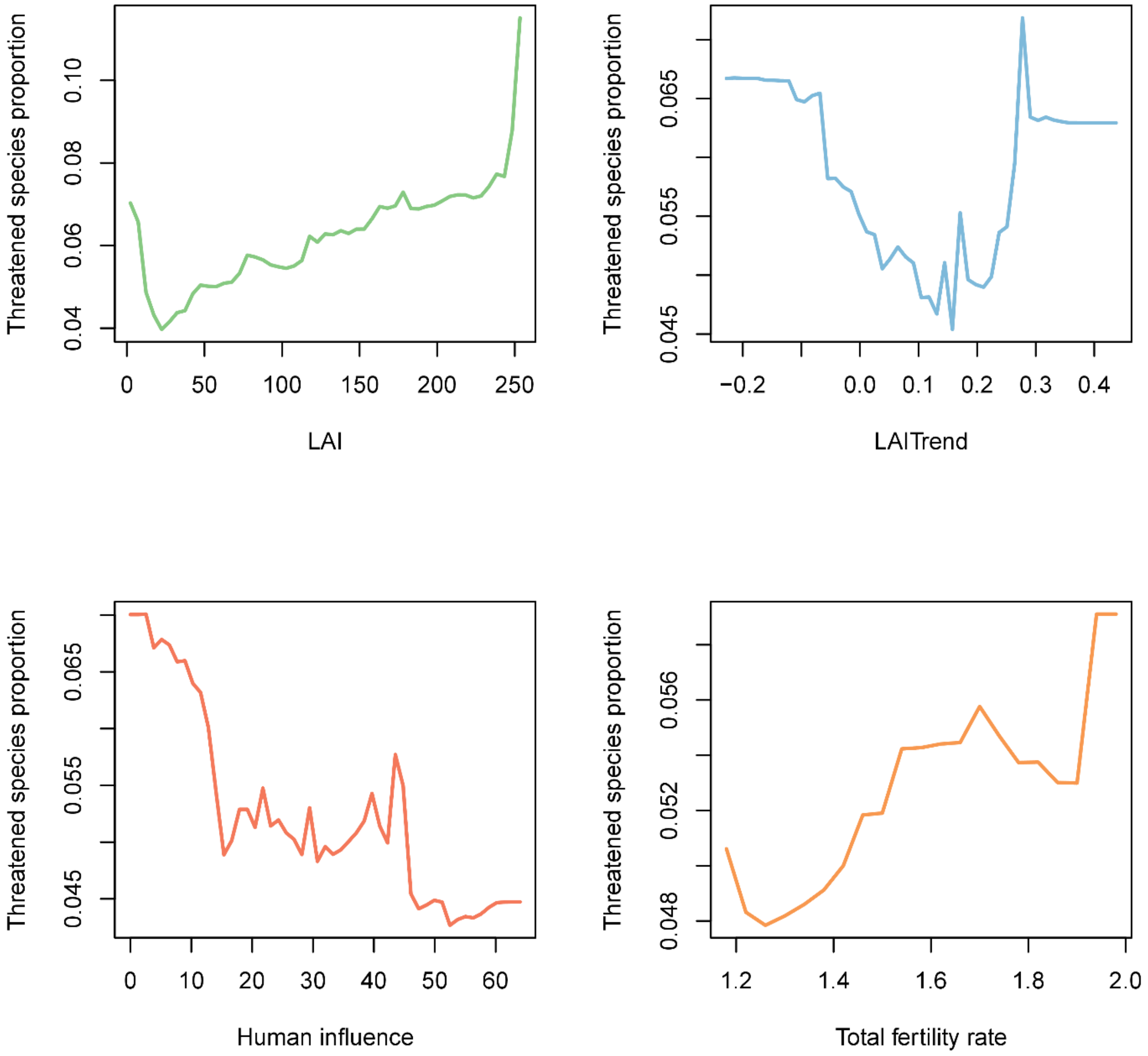

Figure 3 Relationships between the proportion of threatened bird species and potential predictors. Human influence and the total fertility rate were taken from (Esty et al. 2005).

Discussion

Our preliminary analyses clearly show that this database has the potential to explain spatial and temporal patterns in bird species richness and the relative abundance of functional types. Moreover, this database can be easily amended with novel EO-derived variables that are currently being generated in WP2 of the BACI project and ultimately the “Biosphere Atmosphere Change Index” itself. Novel ecosystem variables may explain observed diversity patterns better than LAI if they capture more or different aspects of ecosystem processes.

These preliminary results and the additional potential of upcoming EO variables for specific regions will be presented and discussed in future interactions with managers.

Table 1. Variables included in the database on Natura 2000 bird diversity, land cover, vegetation structure and human influence.

Variable	Description	Source
MemberState	ISO 3166-1 alpha-2 country codes	[12]
SiteCode	Natura 2000 site code	[12]
Richness	Bird species richness	Calculated from [9]
RichnessTrend	Bird species richness trend	Calculated from [9]
ThreatP	Proportion of threatened species	Calculated from [9]
ThreatPTrend	Proportion of threatened species trend	Calculated from [9]
ForestP	Proportion of forest species	Calculated from [9]
ForestPTrend	Proportion of forest species trend	Calculated from [9]
FarmP	Proportion of farmland species	Calculated from [9]
FarmPTrend	Proportion of farmland species trend	Calculated from [9]
CommonP	Proportion of common species	Calculated from [9]
CommonPTrend	Proportion of common species trend	Calculated from [9]
lcAgricultureP	Corine classes 211-244	[8]
lcForestP	Corine classes 311-313	[8]
lcOpenP	Corine classes 321-322	[8]
lcShrubP	Corine classes 323-324	[8]
lcWetlandP	Corine classes 411-423	[8]
lcWaterP	Corine classes 511-523	[8]
lcSemiNaturalP	Corine classes 311-313, 321-324, 411-412	[8]
LAI2001mean – LAI2015mean	Annual LAI means for 2001-2015	Calculated from [13]
LAI2001sd – LAI2015sd	Intra-annual LAI standard deviations for 2001-2015	Calculated from [13]
HII	Human Influence Index	Esty et al. (2005)

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