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

Deliverable 8.5: EO-based maps of the vulnerability of biodiversity

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Overview and aim

The overall goal of D8.5 is to provide EO-based maps of the vulnerability of biodiversity. Specifically, D8.5 aims, at (1) assessing if temporal changes in plant and bird diversity is related to EO-based maps of the Biosphere Atmosphere Change Index (BAC-Index) and (2) produce maps of the vulnerability of biodiversity (as described in MS13).

To achieve these aims we present two analyses. In the first analysis, we explore relationships between ground-based records of temporal change in European bird communities and the BAC-Index. In the second analysis, we illustrate the value of high-resolution EO-data for assessing the vulnerability of biodiversity. Specifically, we use airborne lidar to quantify temporal change in vegetation structure and relate it to ground-based records of temporal change in plant community composition.

BAC-Index and bird community composition

BAC-Index

We used the most recent version of the BAC-Index provided by WP5. This index is based on several ecosystem variables, has a spatial resolution of 0.25 degrees and a temporal resolution of 8 days between 2001 and 2012. The index is calculated using Mahalanobis distance, which is subsequently classified into three classes: normal, potential anomaly and intense anomaly. The anomaly classes were used instead of the continuous Mahalanobis distances as these do not take spatial and temporal autocorrelation into account. Most biodiversity data has much lower temporal resolution, typically one to several years. We therefore aggregated the BAC-Index to a yearly index by summing the original anomaly classes. We used a score of two for an "intense anomaly" and a score of one for a "potential anomaly". Since bird surveys are typically conducted in spring and summer, we calculated these annual BAC-Index between July and July, starting in 2001.

Temporal dynamics in bird communities

For the first exploration of the relationship between temporal changes in the BAC-Index and biodiversity, we used the estimated changes in bird communities across several European countries computed for D4.3 (see D4.3 for details on the data). Briefly, we used bird survey data from 2001 to 2011 and calculated temporal beta diversity (Baselga & Orme, 2012; Baselga & Leprieur, 2015) , which is a measure of community composition change through time. Total temporal beta diversity consists of two components. The nestedness component indicates changes in species richness, while the turnover component indicates changes in species identity. One difference, relative to the product in D3.4, is that we for D8.5 downscaled the data from 0.5 degree to 0.25 degree, in order to match the BAC-Index resolution. This downscaling results in a spatially less dense data set. However, there are still 1,755 unique grid cells for which we have bird data in at least one year, and there are 9,938 "cell years" in total.

Results

The maps of the annually summed anomalies over Europe illustrate the spatial and temporal patterns (Fig. 1). Relating these patterns in the BAC-Index to the temporal changes in bird community composition indicates that areas with larger anomalies also have a tendency towards more temporal changes in bird community composition (Fig. 2). This relationship was mainly evident in areas with high anomaly sums, e.g. 12 or higher.

Furthermore, sites with a high BAC-Index tend to have a higher proportion of species with globally declining population trends (IUCN[1], Fig. 3). This suggests that areas with many and/or large environmental anomalies have bird communities that are, on average, more vulnerable.

In summary, this version of the BAC-Index captures some variance in bird community dynamics. The index is composed of five variables, of which only sensible heat could have a direct physiological effect on birds. The other four variables all strongly depend on vegetation: gross primary productivity, net ecosystem exchange, ecosystem respiration and latent heat. Since vegetation structure, standing biomass and productivity are all well-known drivers of bird population dynamics, it is plausible that the BAC-Index captures important drivers of bird population dynamics. However, more in-depth testing of these relationships will be required and is intended within the BACI framework. One potential obstacle in making mechanistic links between biodiversity measures and this version of the BAC-Index is its relatively coarse spatial resolution (0.25°).

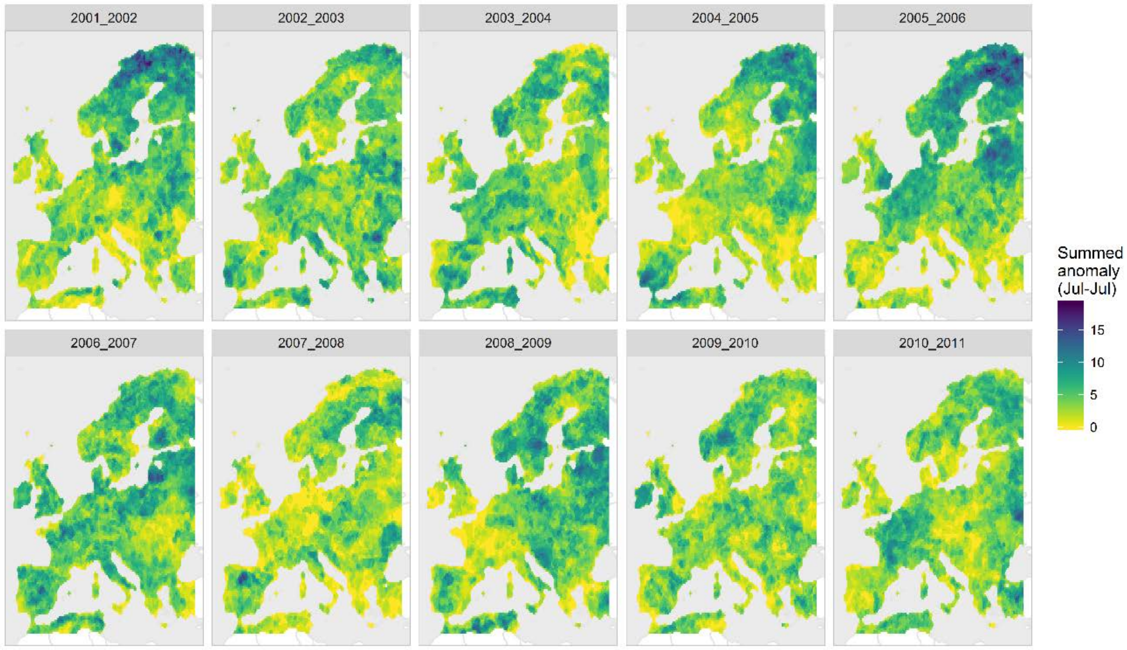

Figure 1 Summed annual ecosystem functioning anomalies (preliminary BAC-Index) for Europe. Intense anomalies and potential anomalies were weighted as 2 and 1 respectively and then summed from July to July, to match the temporal frequency of bird surveys.

[1] http://www.iucnredlist.org/search/link/5a422924-2a5a839e

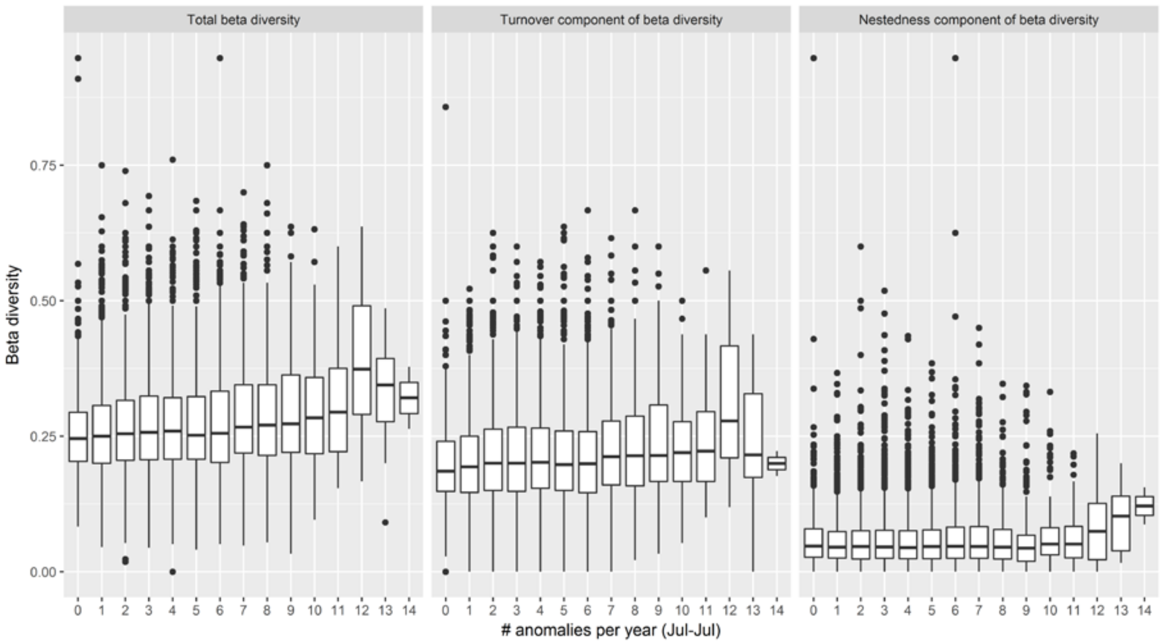

Figure 2 Relationship between compositional change in European bird communities and ecosystem change as represented by a preliminary version of the BAC-Index. Summed annual ecosystem functioning anomalies (preliminary BAC-Index) for Europe. The number of anomalies per year were summed from July to July. Intense anomalies and potential anomalies were weighted as 2 and 1 respectively.

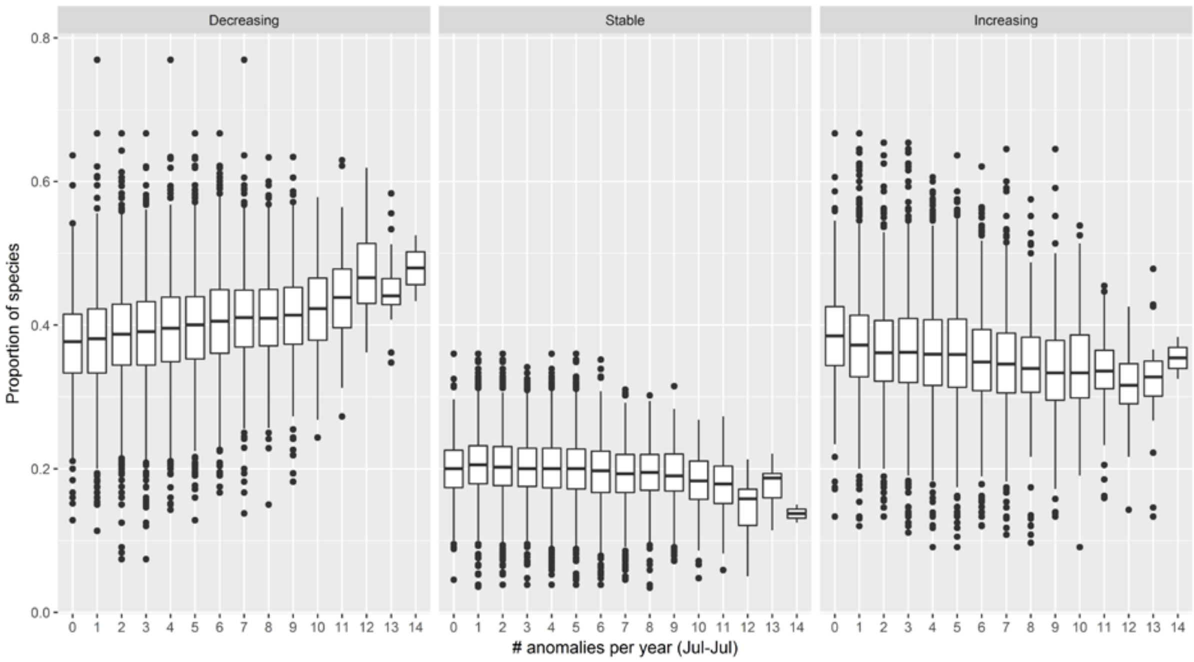

Figure 3 Proportion of species with decreasing, stable and increasing population trends according to the IUCN[2], plotted against ecosystem change as represented by a preliminary version of the BAC-Index. Summed annual ecosystem functioning anomalies (preliminary BAC-Index) for Europe. The number of anomalies per year were summed from July to July. Intense anomalies and potential anomalies were weighted as 2 and 1 respectively.

[2] http://www.iucnredlist.org/search/link/5a422924-2a5a839e

Plant species vulnerability in relation to changing vegetation structure

Previous work has shown that species-specific traits related to competitive ability, predominantly maximum plant height, predict whether species become more common ('winners') or less common ('losers') in Danish Natura 2000 areas (Timmermann *et al.*, 2015) . An overall shift toward taller and more competitive species was observed. In this section, we quantify the actual temporal change in vegetation height using very high-resolution airborne lidar scans. We then link changes in vegetation structure to biodiversity, using data on the temporal turnover of plant community composition in order to explore whether lidar-derived changes in vegetation height can be used as an indicator of plot-level vulnerability. Finally, we extrapolate this lidar-based index of vulnerability to all Danish Natura 2000 areas.

Methods

Biodiversity plots

We used vegetation survey data from the Danish national monitoring network, NOVANA[3]. A total of 31,655 vegetation plots (0.25 m^2) spread over 953 sites were surveyed for vascular plants between 2003 and 2010. All plots were situated in natural to semi-natural habitats. Plots were assigned to EU habitats[4], allowing an estimate of temporal change in vegetation height per habitat type.

LiDAR data

We used two airborne laser scans covering the whole of Denmark. The first campaign, henceforth "2006 scan", was flown in the winter months (leaf-off period) of 2005, 2006 and 2007[5]. The second campaign, henceforth "2015 scan", was flown in the winter months (leaf-off period) of 2014 and 2015[6]. Digital terrain models (DTM) and digital surface models (DSM) were downloaded and vegetation height for both campaigns was estimated by subtracting the DTM from the DSM. Since the 2006 scan had a lower point density (0.45 points m^{-2}) than the 2015 scan (4-5 points m^{-2}), the vegetation height raster layers had a lower resolution in 2006 (1.6 m^2) than in 2015 (0.4 m^2). To harmonise both data sets, the 2015 DTM and DSM rasters were resampled to the 2005 grid using bilinear interpolation.

To estimate temporal change in vegetation height at NOVANA vegetation plot locations, we extracted data from the four nearest 1.6 m pixels, i.e. for a total area of 10.24 m^2 around each plot. Finally, we quantified temporal change in vegetation height as the difference between the 2005 and the 2015 vegetation height estimates in each 10.24 m^2 plot.

Results

Within the NOVANA vegetation monitoring plots we observed a wide range of change in vegetation height (Fig. 4). Although the median change was close to zero for most habitat types, increases and decreases in vegetation height were detected in plots within each habitat. Some increases and decreases are very large and may partly be explained by data artefacts, e.g. resulting from the resampling of the finer 2015 grid to the coarser 2006 lidar grids. Nonetheless, increases in vegetation

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[3] http://mst.dk/natur-vand/overvaagning-af-vand-og-natur/

[4] http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf

[5] https://kortforsyningen.dk/sites/default/files/old_gst/DOKUMENTATION/Data/dk_dhm-2007_terraen_okt_2014.pdf

[6] https://kortforsyningen.dk/sites/default/files/old_gst/DOKUMENTATION/Data/dk_dhm_punktsky_v2_jan_2015.pdf

height of approximately 1 m can have significant effects on biodiversity in (semi-)open habitats (Timmermann *et al.*, 2015) .

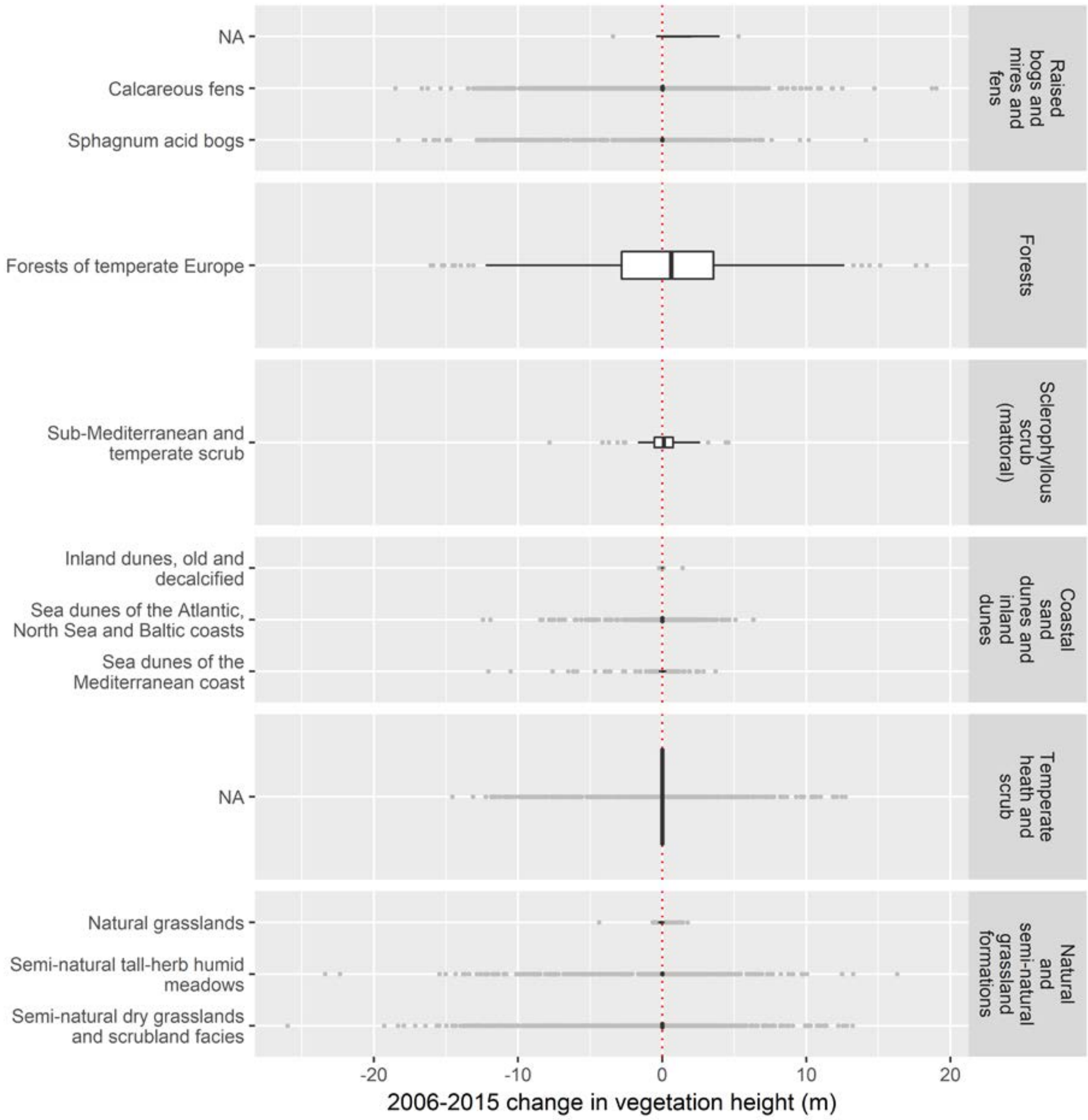

Figure 4 Lidar-derived change in vegetation height at NOVANA monitoring plots. Sites were grouped by EU habitat type, with coarse-level classes shown in the panels on the right, and fine-level classes shown on the y-axis. The fine-level classes are "NA" when were not assigned a fine-level class. The height of the boxes is proportional to the number of vegetation plots within a habitat type.

Building on the observation that declining plant species in Danish Natura 2000 areas are typically short, we use our lidar-based observations of temporal change in vegetation height to propose a vulnerability index for NOVANA plots. The vulnerability index is based on change in vegetation height at a site and the proportion of "loser" species at a site (Fig 5).

The thresholds are simple linear functions, based on expert ecological knowledge and results from previous work (Timmermann *et al.*, 2015) . The rationale behind "Medium" vulnerability (the orange line in Fig. 5), is that an >1 m increase in vegetation height in (semi-)open habitats is substantial and may indicate woody expansion, which is likely to result in the decline of herbaceous species. When a larger proportion of the community consists of declining ("loser") species, a smaller increase in vegetation height is likely to lead to species loss. Hence, the threshold lines decrease as the proportion of declining species increases.

A similar rationale underlies the threshold line for "High" vulnerability, which starts at increased vegetation height of 5 m. Increases of 5 m or more over a nine-year period are extreme in (semi-)open habitat and therefore demand further investigation.

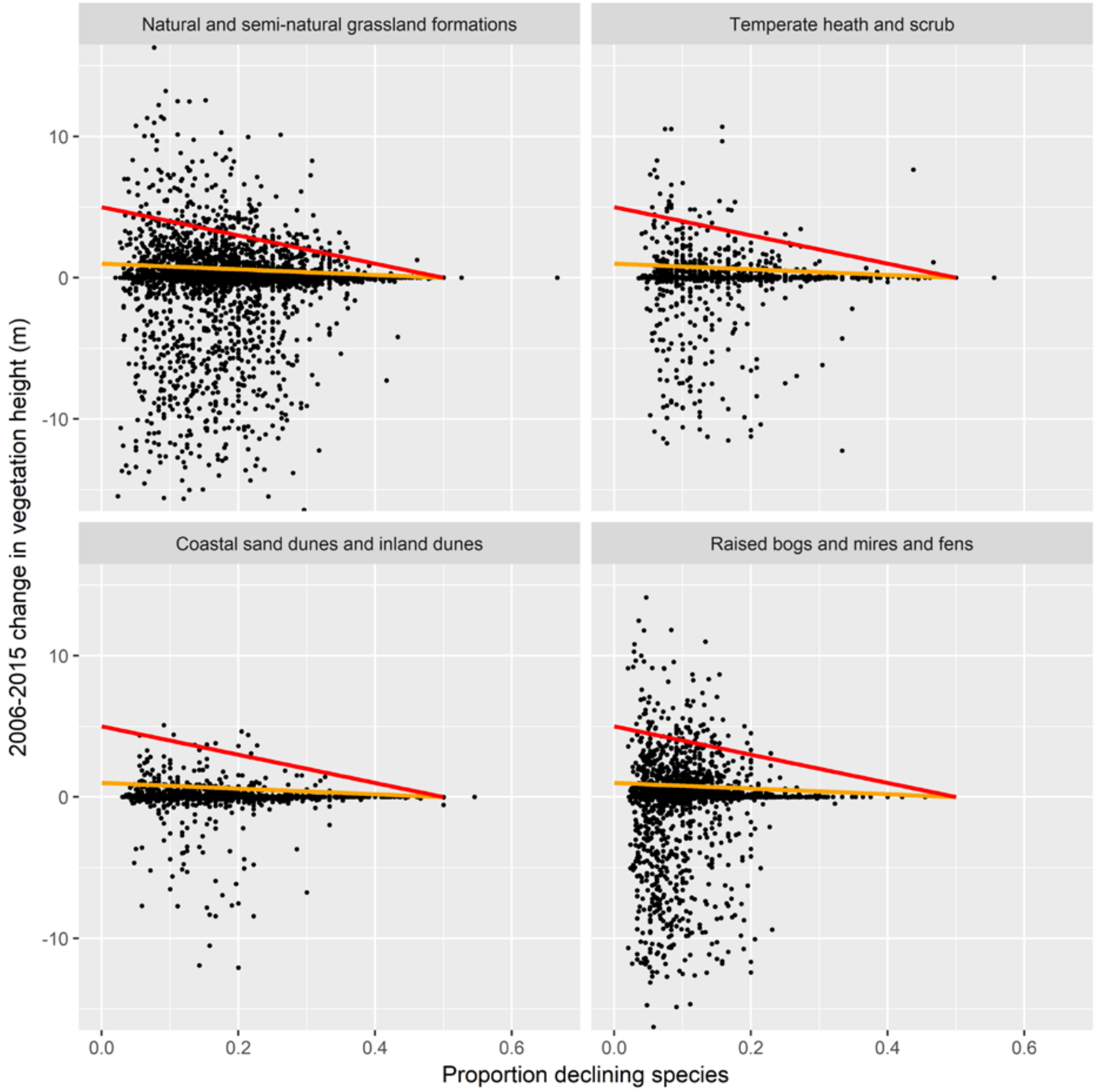

Figure 5 Lidar-derived change in vegetation height plotted against the proportion of "loser" species at NOVANA monitoring plots. Plots above the red line fall into vulnerability class "High", as they have large increases in vegetation and/or a large proportion of declining species. Plots above the orange line fall into vulnerability class "Medium" and points below the orange line fall into vulnerability class "Low". The function for the "Medium" (orange) threshold line is $y = -2x + 1$, and the function for the "High" (red) threshold line is $y = -10x + 5$. See text for an explanation of the thresholds for vulnerability classes. Only (semi-)open habitats were considered.

In each of the four considered open habitats, the majority of plots fall into the "Low" vulnerability class (Fig. 6). However, especially in grasslands and mires a substantial number of plots have moderately or highly vulnerable to losing species.

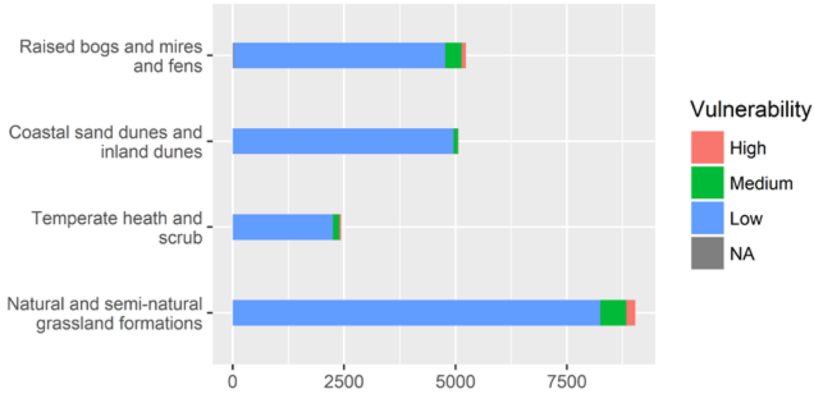

Figure 6 Proportion of NOVANA plots within each vulnerability class for (semi-)open habitats.

Finally, we quantified temporal change in vegetation height for each of the four (semi-)open habitats within Danish Natura 2000 areas (Fig. 7). In contrast to the NOVANA monitoring plots, median change was distinctly negative for forests and shrublands. For peat bogs, approximately 25% of pixels increased in height by more than 0.5 m.

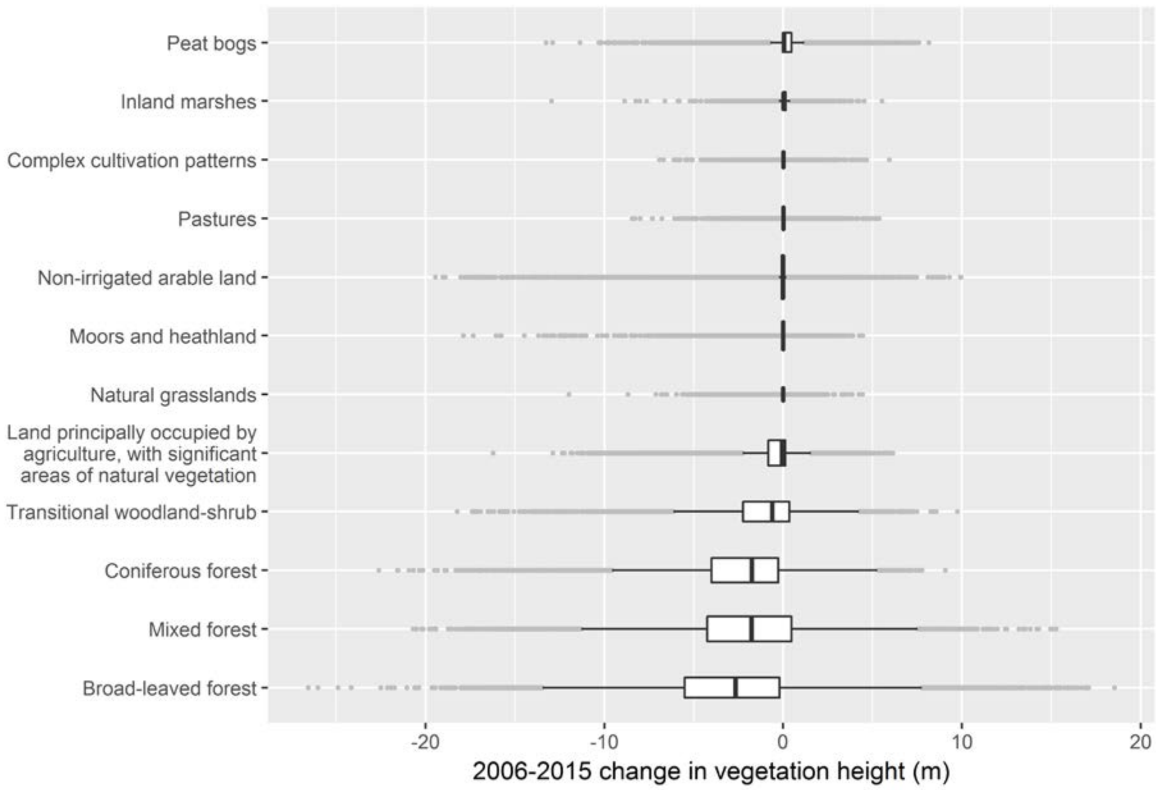

Figure 7 Lidar-derived change in vegetation height for selected land cover classes in Danish Natura 2000 areas. Land cover classes were taken from the 2012 CORINE land cover product[7]. The height of the bars is proportional to the number of pixels included in each land cover class.

A visual assessment for a bog habitat confirms that growth and/or expansion of woody plants causes the increase of lidar-derived change in vegetation height (Fig. 8).

[7] https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012

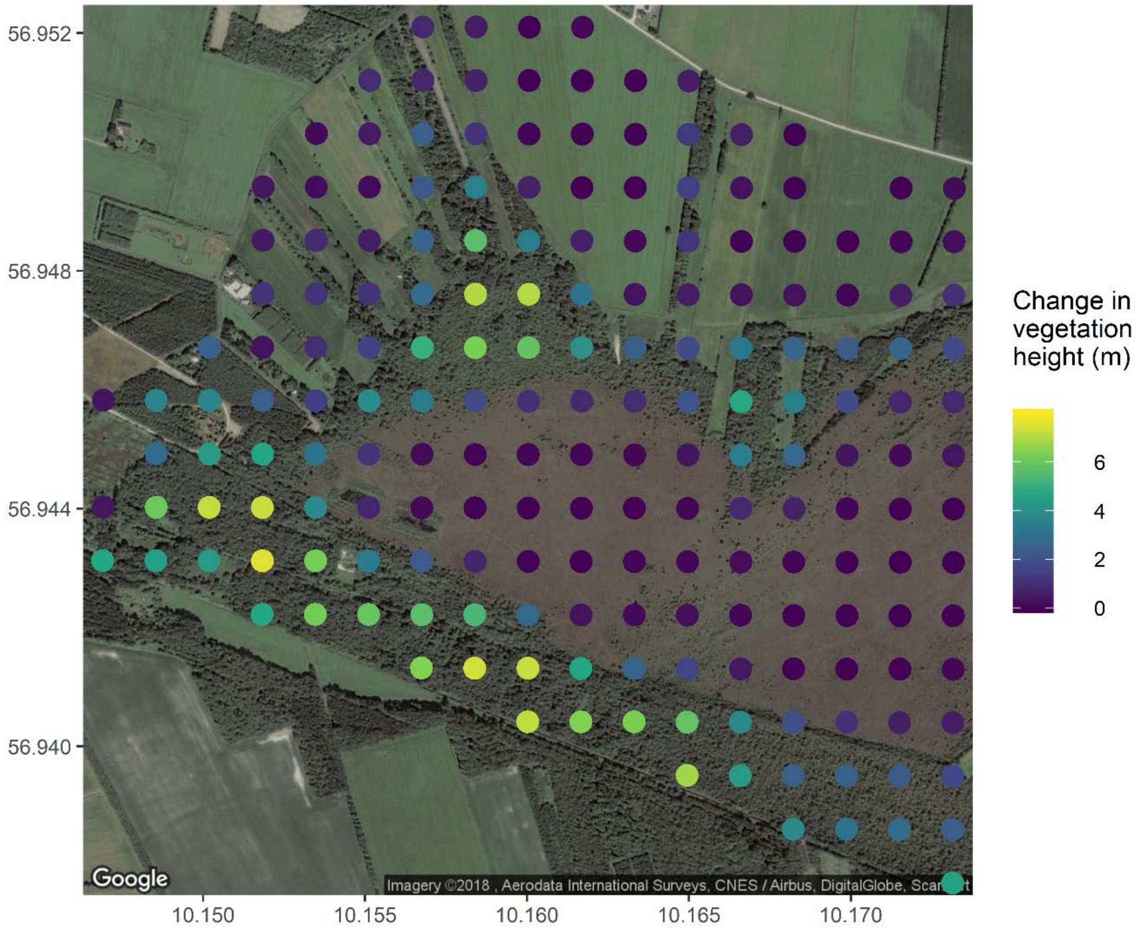

Figure 8 Satellite image of a bog in a Danish Natura 2000 area (Lille Vildmose). The points represent lidar-derived change in vegetation height between 2006 and 2015. Each dot represents a 3.2×3.2 m pixel. Around the perimeter of the bog it is clear that shrubs and trees cause the observed increase in vegetation height.

Conclusion

Although more work will be needed to develop the BAC-Index into a fully-fledged early warning system, the relationships between the BAC-Index and bird community-level and population-level change provides a promising outlook. Specifically, we find that areas with larger environmental anomalies (as represented by the BAC-index) also tend to have more temporal changes in bird community composition, and that sites with a high BAC-Index tend to have a higher proportion of bird species with globally declining population trends. One current limitation of the BAC-index used here is the relative low resolution compared to the spatial resolution biodiversity change.

To illustrate the value of higher resolution data, we show that airborne lidar, a form of EO still novel to ecology and environmental monitoring, holds great promise for monitoring vegetation structure and associated change in plant community composition. High-resolution data from the sentinel program is expected to provide a similar capacity to detect environmental change at a higher temporal resolution. Vegetation structure and plant community composition typically have large effects on overall biodiversity. Therefore, with further development and testing, future high-resolution versions of the BAC-index may become an effective and efficient component of ongoing biodiversity monitoring. Although such an index will not remove the need for ground-based studies and monitoring, it could direct their design and study sites by identifying areas undergoing large changes.

References

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