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D09.3 Climate change indicators

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Publishable Executive Summary

Shifts in community composition represent one of the major effects of climate change on biodiversity. However, it is often difficult to quantify these changes due to a lack of long-term data and suitable indicators. The aim of the present work was to fill this gap by developing and testing climate change indicators using long-term vegetation data from eLTER sites. Two indices were developed that are based on the overall distribution of vascular plant species and that reflect their climatic niches. These indices combine information on the coverage of floristic zones, the altitudinal distribution and the occurrence of plant species along the phytogeographic continentality gradient. A summer and a winter index was developed for each species as climate warming may affect species adapted to mild winters and hot summers differently. Community indices were calculated based on species indices for six test data sets to evaluate their variability in space and across time, to test different calculation methods and to compare them with already existing indicators. Both newly developed community indices showed a pattern of geographic variation that reflects major climatic gradients in Europe. In contrast, community indices hardly varied across time indicating that the plant communities under study were relatively stable over a time period of approximately 20 years. Summer index and winter index were not correlated to each other. While the summer index showed a positive relationship with the traditionally used Ellenberg temperature index no such relationship was found between winter index and Ellenberg temperature index. The inclusion of species abundance or frequency in the calculation of community indices instead of using species lists only affected the result. While overall geographic variation was relatively stable, differentiation at smaller scales depended on the choice of method. Data download via the eLTER virtual access scheme was comfortable and the provided data sets could be used for the analysis without major adaptations. Future work should extend the number of data sets and time series which are becoming increasingly available through the eLTER virtual access scheme.

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1 Introduction

Changes in the composition of species communities represent a major consequence of climate change. Such changes have been shown to occur in a wide range of ecosystems, for example terrestrial, marine and freshwater systems (Daufresne et al. 2003; Jourdan et al. 2018) and to affect a variety of taxonomic and functional groups. To quantify climate induced changes in community composition indicators are required. A well-known example is the community temperature index (CTI) which reflects the composition of a species community with regard to the thermal niche of the species it contains. Basically the CTI represents the abundance-weighted mean of single species temperature indices (STIs) which in turn represent the mean temperature over of the species range (Devictor et al. 2008). Increases in CTI that go along with rising temperatures have been found for butterflies and birds (Devictor et al. 2012; Van Swaay et al. 2010; Zografou et al. 2014) and at different spatial scales.

Existing indicators that describe the relationship between climate and plants were developed for general ecological studies and purposes and in a period when climate change was not on the research agenda. The most prominent indicators are Ellenberg values which were developed for the flora of central Europe and in particular for Germany (Ellenberg 1974; Ellenberg and Leuschner 2010). Later similar values were specified for other European regions such as Switzerland (Landolt et al. 2010), parts of Greece (Böhling et al. 2002) and Italy (Guarino et al. 2012; Pignatti et al. 2005). The conceptual basis of these values are regional ecological niches of plant species rather than niches at a continental or global scale. Community indicators based on Ellenberg temperature values have been used to analyze the impact of climate change on plant communities at regional scales (Roth et al. 2014) but their spatial scope remains limited. Further, for many plant species there are no Ellenberg indices available or they have been classified as indifferent.

An alternative source of information on the climatic niche of plants are the descriptions of distribution areas of plants (range formulas) developed by the Halle school of plant geography (Jäger 1968; Meusel et al. 1965-1992). These formulas include the zonal distribution of the plant species, their altitudinal ranges and their distribution along the phytogeographic continentality gradient. Range formulas are available for more than 4000 plant species (Jäger 2016). The phytogeographic continentality gradient and borders of floristic zones in the northern hemisphere are shown in Figure 1.These formulas do not rely on expert knowledge but on mapped total distributions of plant species, and they are not restricted to a certain country or continent. Ellenberg (1974) partly used these formulas to develop the temperature and continentality index but also considered local distributions of plant species and the microclimates within their central European habitats. Therefore, Ellenberg - as well as Landolt values represent a hybrid between ecological and plant geographical indicator. Here we used range formulas to develop indices that consider the climatic niche of plant species over their entire distribution. Walther (2002) showed that species originating from oceanic regions where winter temperatures are relatively high and summer temperatures low benefit from milder winters, e.g. evergreen broad-leaved species like *Hedera helix* and *Ilex aquifolium*. In contrast, species found in more continental climates with large temperature differences between summer and winter should benefit from higher summer temperatures. Examples for such species are *Bromus inermis*, *Chenopodium strictum* and *Amaranthus retroflexus*. Given the different responses of plant species to summer- and winter temperatures we developed a winter index and a summer index. The aim is to use these indices to analyze climate-driven changes in plant community composition across time. This report tests an initial version of indicators to verify the validity of the concept. Specifically the following questions are addressed:

(i) Do community indices differ in space?

(ii) Is there variability across time?

(iii) How are indices interrelated and how do newly developed indices correspond to traditional ones?

(iv) Does the level of detail in eLTER-vegetation data affect the outcome of index calculation?

(v) Is the eLTER virtual access scheme in its current form sufficient to provide data necessary for such analyses?

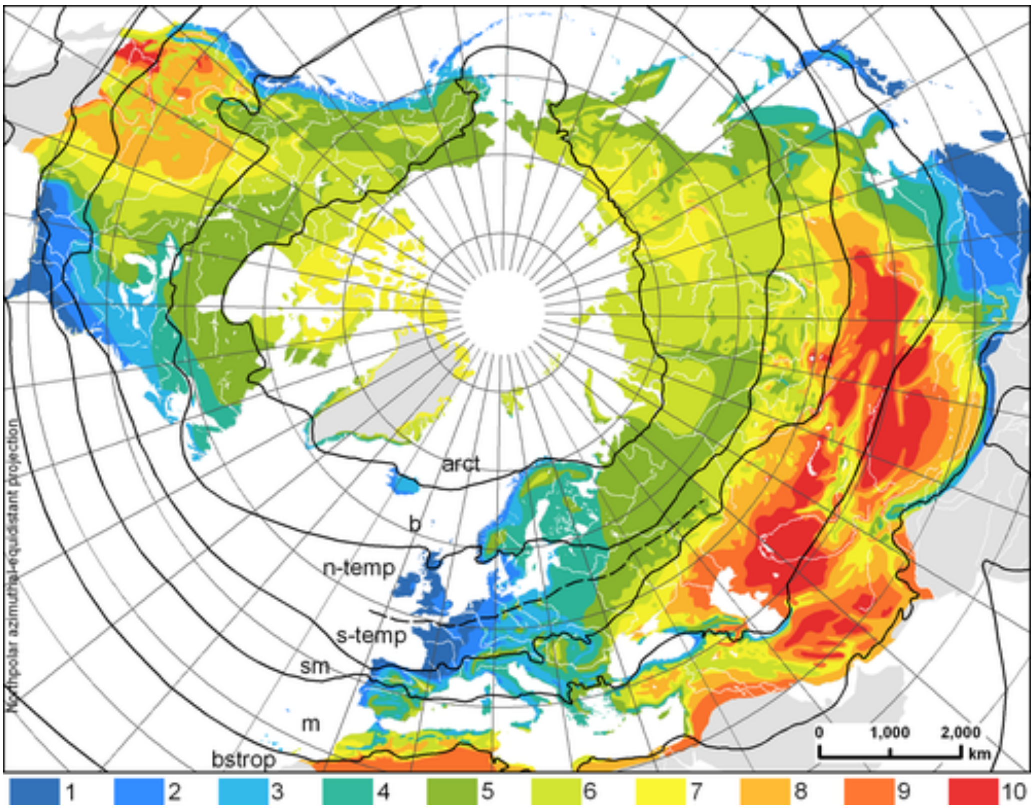

Figure 1 Phytogeographic continentality according to Jäger (1968) obtained from Berg et al. (2017). Colors indicate ten levels from 1 (low continentality) to 10 (highest continentality). Borders of floristic zones are indicated as black lines. For abbreviations see Table 1.

2 Methods

2.1 Calculation of species indices

First, for each plant species the information on its distribution, encoded by the range formula, was translated into numerical values.

The floristic zones received values from 1 (coldest zone) to 7 (warmest zone, see Table 1). To simplify matters, northern and southern temperate zones were not distinguished. Afterwards the mean value of floristic zones where a species is present was calculated. An important additional factor is the altitudinal range of a species specified in the range formula. There are three main categories that need to be taken into account when deriving climatic niche information: alpine, subalpine and montane zone. For example, a species that is present in the meridional zone but only within the alpine altitudinal range has not the same climate niche as a species of the meridional zone that can be found in the planar altitudinal range only. For this reason, the sum of zonal values was reduced by a value for the altitudinal range (Table 2). For example, a species of the meridional zone gets the zonal value of 5 (Table 1). If this species is only present in the alpine range the value is reduced by 3 (Table 2). The corrected value (2) was then used in subsequent calculations.

Table 1 Numerical values assigned to floristic zones shown in Figure 1

Floristic zone	Abbreviation	Assigned value	Mean Temperature (°C)
Arctic	arct	1	-14,3
Boreal	b	2	-5.3
Temperate	temp	3	4,5
Submeridional	sm	4	8,6
Meridional	m	5	12,7
Boreosubtropic/ Austrosubtropic	boreostrop/ austrotrop	6	25/ 22
Tropic	trop	7	24,8

Table 2 Numerical values assigned to altitudinal zones.

Altitudinal zone	Abbreviation	Assigned value
Montane	mo	1
Subalpine	salp	2
Alpine	alp	3

The continentality range of a plant was extracted in a similar way as the zonal information and translated into a value for continentality and oceanity, respectively (Table 3), using the scale provided by the range formula. Continentality according to (Jäger 1968) is given ten categories from 1 (low continentality) to 10 (highest continentality). Values for oceanity represent the opposite of continentality values (Table 3). For each species mean values for continentality and oceanity were calculated.

Table 3 Numerical values assigned to continentality and oceanity.

Plant geographic contintentality	Assigned value for continentality	Assigned value for oceanity
c1	1	10
c2	2	9
c3	3	8
c4	4	7
c5	5	6
c6	6	5
c7	7	4
c8	8	3
c9	9	2
c10	10	1

Two indices were calculated that combine climatic niche information from the floristic zones covered (mean values of floristic zones corrected by altitude) and the niche information that can be derived from the continentality range (mean continentality and oceanity). To calculate the summer index the mean values for floristic zones (corrected by altitude) and continentality were added and their sum was divided by two. The winter index was calculated by dividing the sum of mean floristic zone and oceanity by two. Table 4 shows examples for the index calculation for species with differing climatic niches. Based on these species indices it is possible to calculate community indices (see 2.2).

Table 4 Examples for index calculation using plant species with different climatic niches. Area formulas were derived from Jäger (2016).

Species	Area formula	Summer index	Winter index
Gentiana clusii	sm/alp-stemp/dealp·c2-3EUR	1,75	4,75
Carex sempervirens	sm/alp-stemp/dealp·c2-3EUR	1,75	4,75
Ilex aquifolium	m/mo-temp·c1-2EUR	2,5	6,5
Fagus sylvatica	m/mo-temp·c1-3EUR	2,75	6,25
Hedera helix	sm-temp·c1-2EUR	3,25	6,25
Koeleria macrantha	strop/salpAM-mtemp·c2-8CIRCPOL	4,5	5
Festuca rupicola	sm-temp·c4-7EUR-WAS	4,5	4,5

2.2 Test of community indices using vegetation data derived via the eLTER-VA scheme

Six data sets were used to calculate community indices, to assess their variability and their relationship to traditional indicators. Of the datasets used, four were downloaded via the eLTER virtual access scheme (Gårdsjön, Randu Meadows, Rhine-Main-Observatory, Zöbelboden) whereas two (Bayreuth, Gimritz) were derived from an internal data base located at Helmholtz Centre for Environmental Research in Halle (Germany). These datasets cover a zonal and continentality gradient, different altitudes and habitats (Figure 2, Table 5).

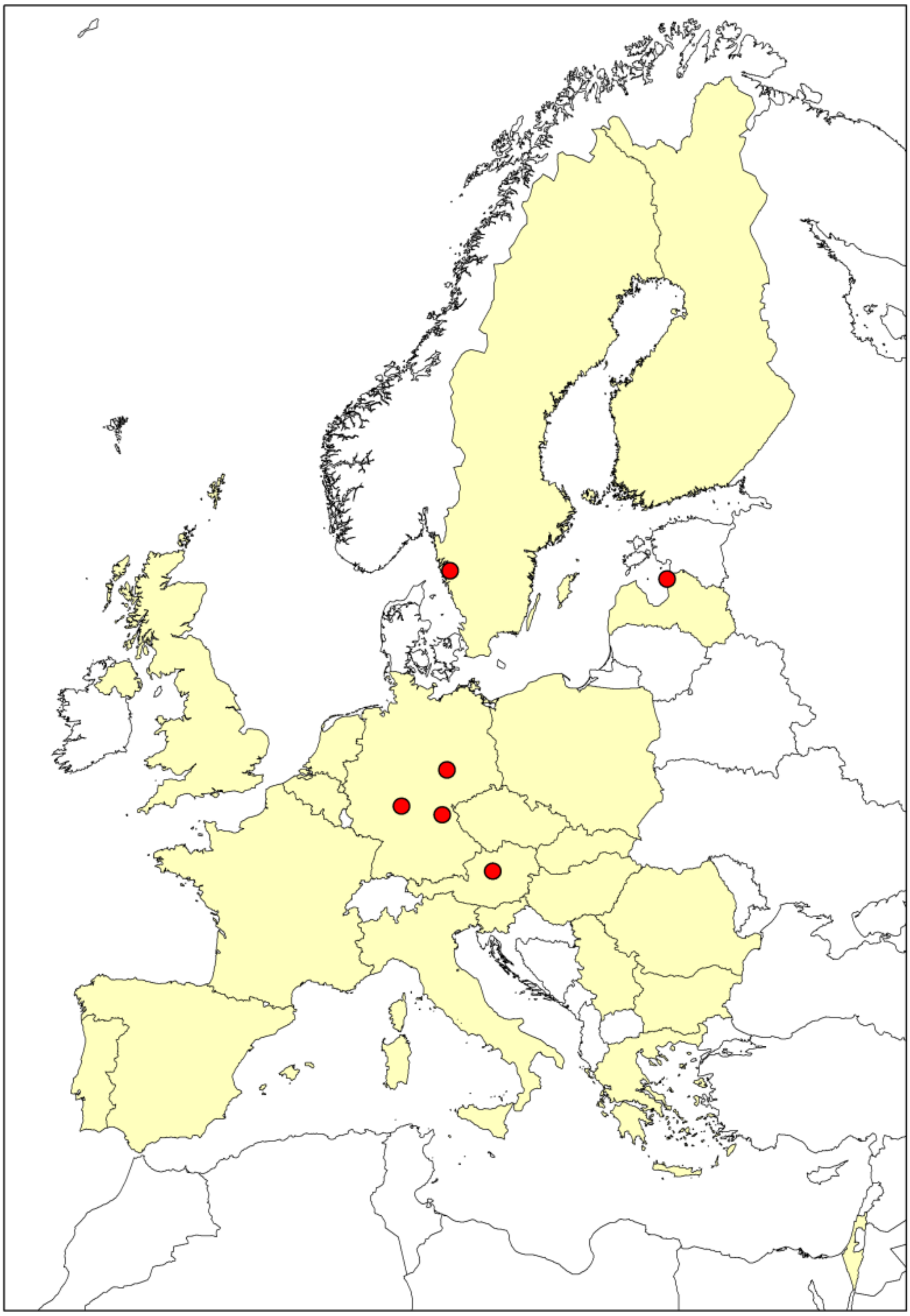

Figure 2 Location of test data sets (red dots) in Europe. Countries contributing to the eLTER site network are highlighted in yellow.

Table 5 Characteristics of test data sets (from north to south).

Site (LTER-code)	Country	Coordinates	Mean elevation (msl)	Mean annual Temperature (°C)	Habitat	Number of plant species	Time period used for spatial analysis	Time period used for temporal analysis
Gårdsjön (LTER_EU_SE_012_001)	Sweden	Lat 58.054 Long 12.018	120	7.1	Forest	9	2013	-
Randu Meadows (LTER_EU_LV_003)	Latvia	Lat 57.800 Long 24.333	1	5.68	Grassland	153	2012	1996-2012
TERENO Gimritz (LTER_EU_DE_002_003)	Germany	Lat 51.561 Long 11.848	117	8.78	Grassland	24	2016	-
Rhine-Main-Observatory	Germany	Lat 50.267 Long 9.269	110	9.45	Forest	55	2012	-
Bayreuth	Germany	Lat 49.916 Long 11.583	355	8.2	Grassland	42	2016	-
Zöbelboden (LTER_EU_AT_003)	Austria	Lat 47.842 Long 14.444	700	7.2	Forest	322	2014	1993-2014

Data sets from the period 2012-2016 were used to assess the spatial variability of community indices (Table 5). For two sites (Randu Meadows and Zöbelboden) time series were analyzed. For the spatial assessment community indices were calculated using three different methods:

(i) Based on species presence per site
(ii) Based on species presence per sub plot per site
(iii) Based on abundance weighted species presence per sub plot per site

The main aspect of these methods is that rare species have the highest weight in method (i), intermedium weight in method (ii) and lowest weight in method (iii). For the time series community indices were calculated using method (ii). Finally the newly developed community indices were tested for interrelationships and for their relationship with mean Ellenberg Temperatures values.

3 Results

3.1 Test of index variability in space

Values for mean floristic zone, continentality, oceanity, summer index, winter index and Ellenberg temperature index differed considerably among the six investigated sites (Figure 3), with the extent of the differences depending on the index and the location of the site. The summer index was highest at Gimritz and Randu Meadows whereas lowest values were found in Gårdsjön and Zöbelboden. Maximum values of the winter index were obtained for the Rhine-Main-Observatory and Zöbelboden. On the other hand the winter index was lowest in Gårdsjön and Randu Meadows.

3.2 Test of index variability across time

The development of mean floristic zone, continentality, oceanity, summer index, winter index and Ellenberg temperature index across time is shown in Figure 4 and Figure 5. There was no obvious trend in any particular direction over time periods of 20 years (Zöbelboden) and 18 years (Randu Meadows). Variability among subplots was high compared to variability across time as indicated by relatively large standard deviations. Variability across time was more pronounced at Randu Meadows (grassland site) compared to Zöbelboden (forest).

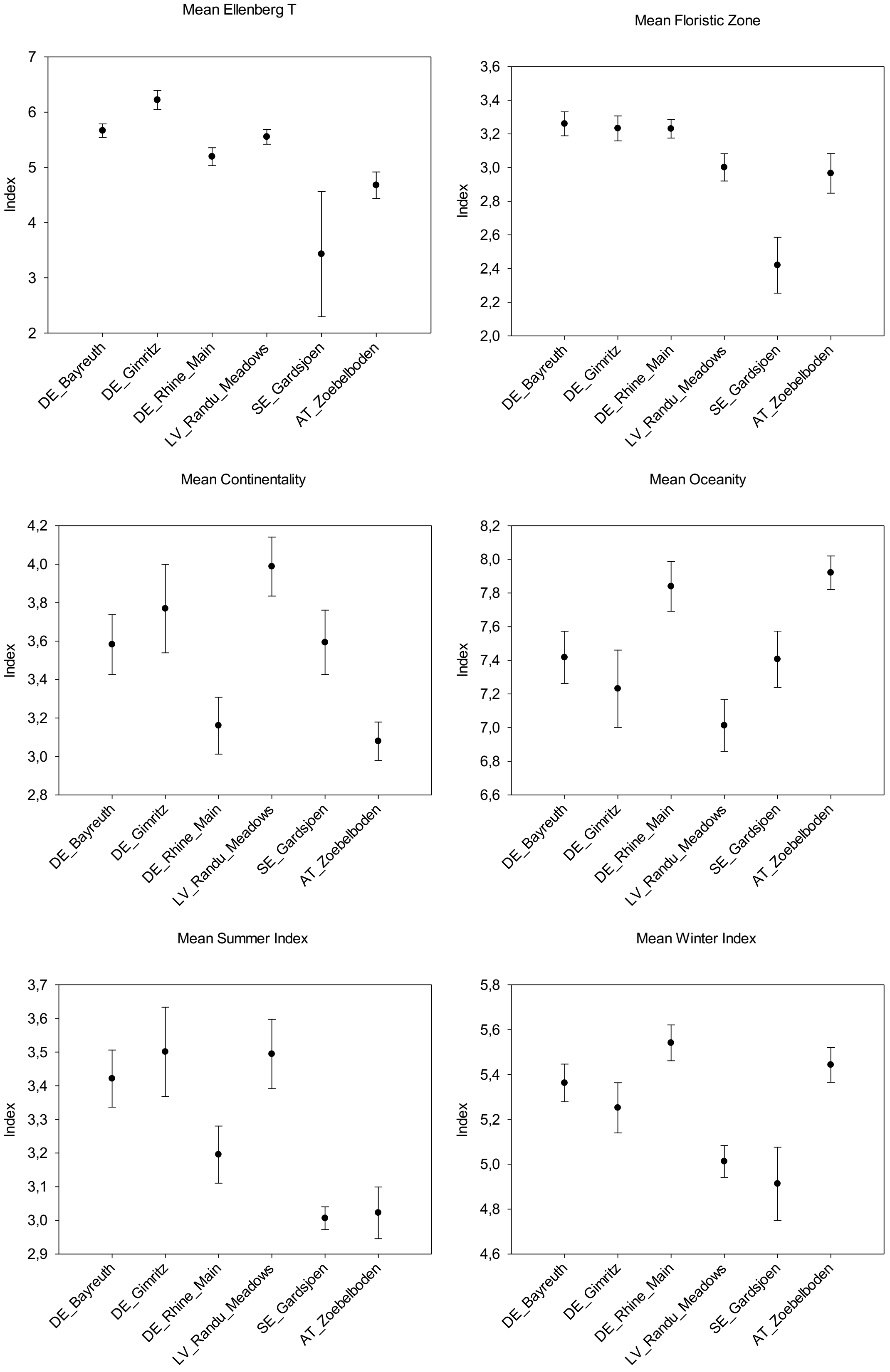

Figure 3 Variability of community indices among six European sites using method (ii). Standard deviations are related to variability among subplots.

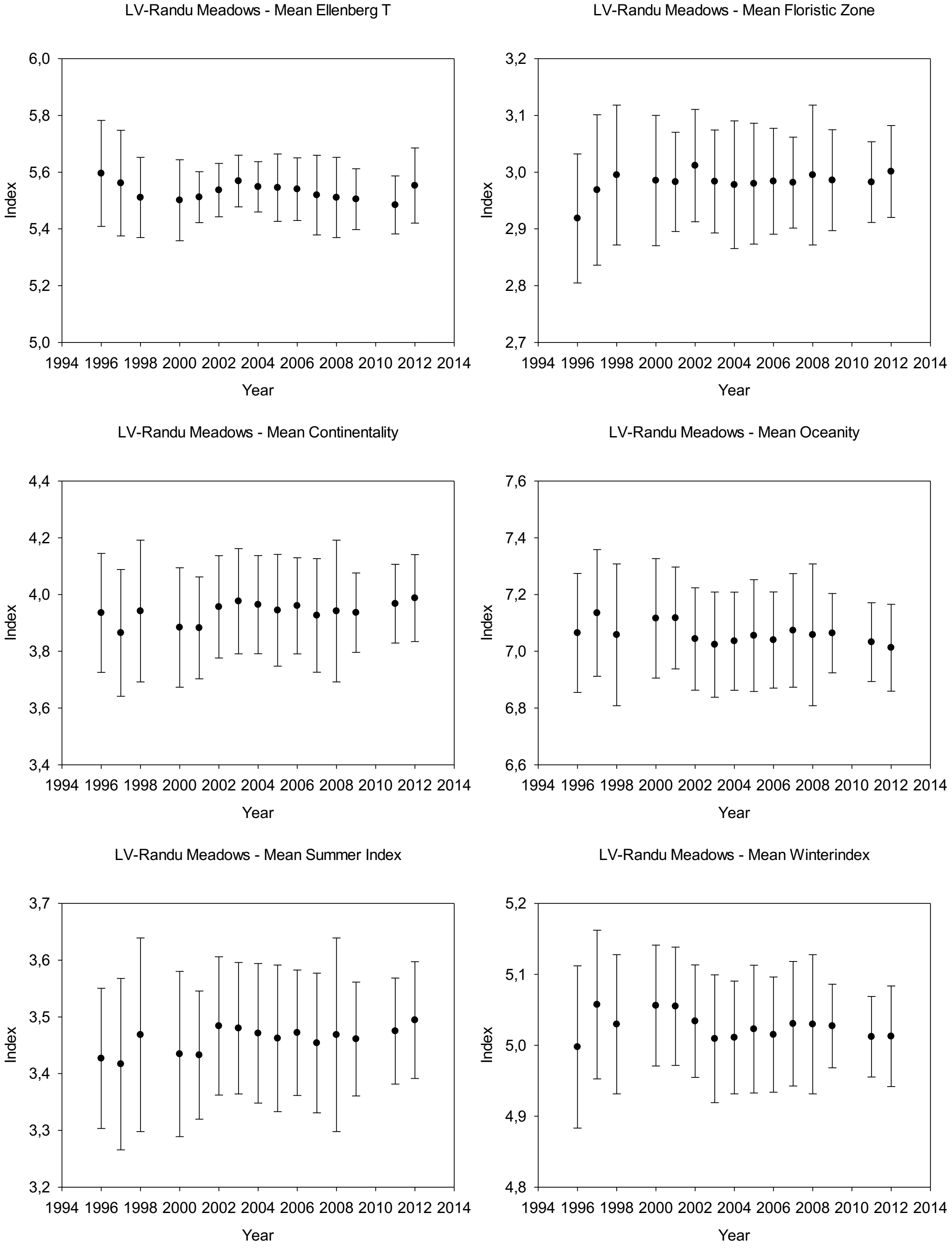

Figure 4 Temporal variation of community indices from eLTER site Randu Meadows. Standard deviations are related to variability among subplots.

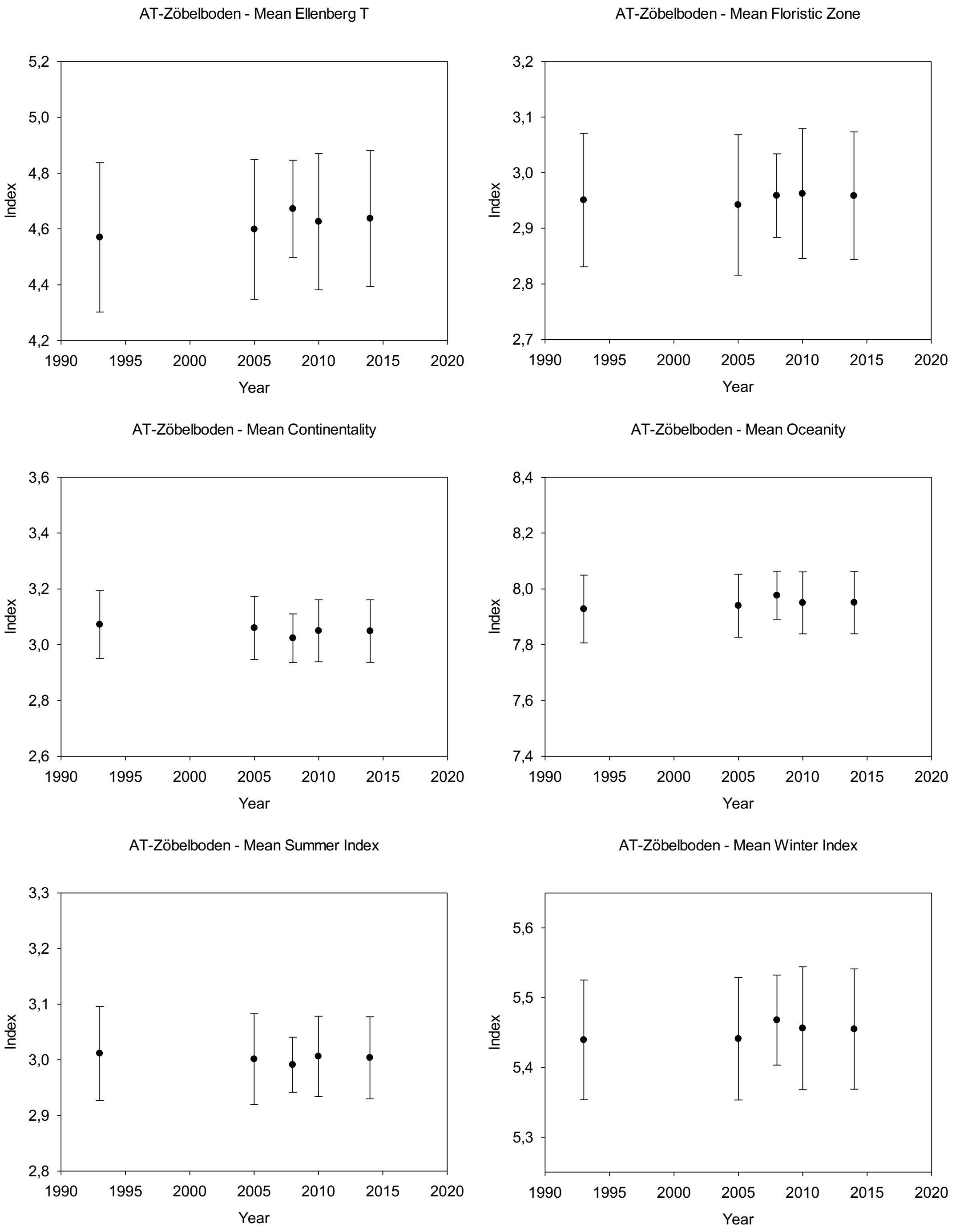

Figure 5 Temporal variation of community indices from eLTER site Zöbelboden. Standard deviations are related to variability among subplots.

3.3 Interrelations among indices

One aim of this study was to investigate how the newly developed community indices are related to each other and how hey correspond to the traditionally used Ellenberg temperature index. Summer index and winter index were not correlated (Figure 6). The Ellenberg Temperature index showed a positive relationship with the summer index but not with the winter index (Figure 6).

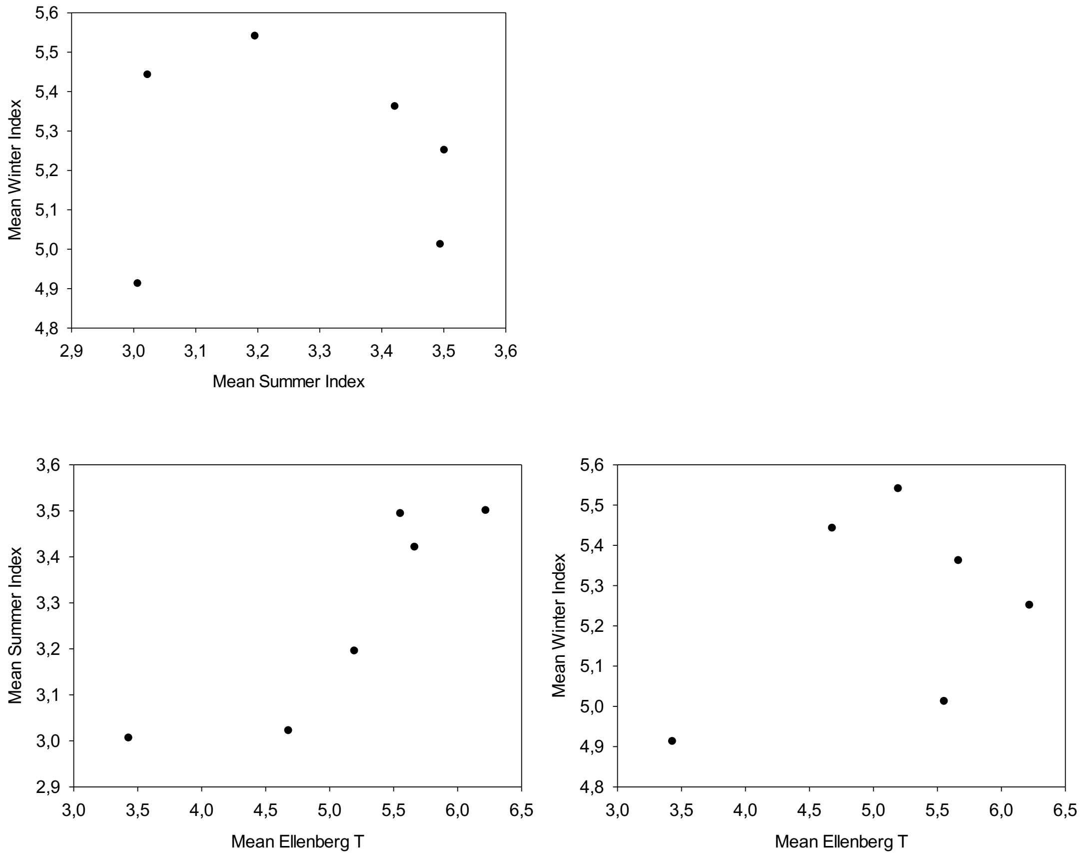

Figure 6 Relationships between Ellenberg temperature index, summer index and winter index.

3.4 Comparison of different methods

Community indices were calculated based on (i) species presence per site, (ii) species presence per subplot per site and (iii) abundance weighted species presence per subplot per site (Figure 7). The degree of detail in the vegetation data affected the result for both indices. However, there was no bias towards a certain direction. The choice of the method also affected the pattern of variability among sites. While the differentiation of both indices from distant and climatically different locations was hardly affected by the choice of method, the differences between nearby locations became less clear, e.g. between sites in Germany.

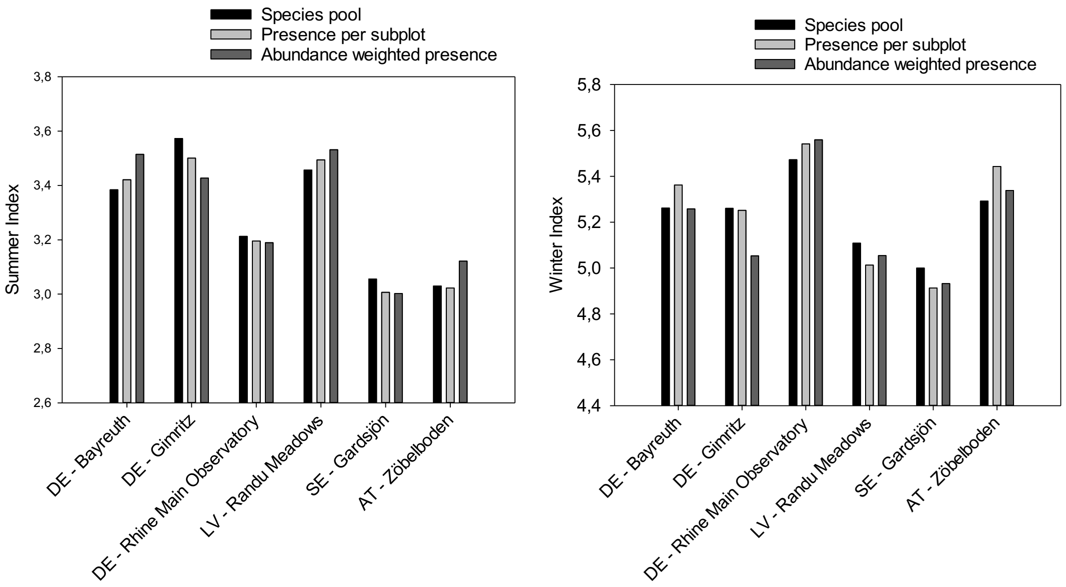

Figure 7 Summer- and winter index based on different levels of detail in the vegetation data.

3.5 Functionality of the eLTER virtual access scheme

Four of the six datasets were obtained via the eLTER virtual access scheme. These data sets along with their metadata could be quickly identified in the database DEIMS (https://data.lter-europe.net/deims/). Download of raw data using the provided B2Share link was comfortable and not restricted in any way. The data tables were well documented and could be used for analysis without major adaptations. Minor difficulties were due to different plant taxonomies used in different countries. One data set contained deposition data and meteorological data along with vegetation data in a single table. Although the different parameters could be easily distinguished they should be documented as separate data sets in the future to enhance clarity.

4 Discussion

The two newly developed community indices showed considerable variation among selected eLTER-sites. This variation increased with spatial distance and altitudinal differences. The pattern of differentiation largely met the expectations. The highest value of the summer index was obtained for the eLTER-sites Gimritz and Randu Meadows which are both dominated by grassland communities of continental climates[1]. Low summer indices were characteristic for Gårdsjön and Zöbelboden. While at the first site the low index was mainly due to plants distributed in generally colder climates (low mean for floristic zone), a high value for oceanity caused the low summer index at the latter site. The maximum values for the winter index at the Rhine-Main-Observatory and Zöbelboden was due to plant communities adapted to oceanic climates. In contrast, low winter indices for Gårdsjön and Randu Meadows were due to low index values for floristic zone and low oceanity, respectively. In general the results seem to be influenced by microclimates of special habitats as well as microclimatic gradients within sites.

Compared to spatial variation, variation of indices across time was low for the two sites investigated in more detail. There was no obvious trend in summer- or winter index and variability among years was low as well. It may be possible that a period of 18 and 20 years, respectively, is not sufficient to detect plant community changes that can be attributed to climate change. Variability among years appeared to be slightly larger at Randu Meadows than at Zöbelboden. This may be due to the fact that community dynamics in meadows is generally higher than in forests. However, a comparison of both data sets is difficult due to different observation frequencies. In the present work, variation of community indices across time was investigated using method (ii). Including species abundance in the index calculation (method iii) may lead to different results.

Summer index and winter index were not related across sites. On one hand this reflects the mode of index calculation (values for oceanity represent the opposite of those for continentality), on the other hand both indices are determined by the gradient in continentality across test sites. There was a positive relationship between the Ellenberg temperature index and the summer index but no such relationship with the winter index.

The comparison of three different methods showed that the degree of detail in the vegetation data may affect index calculation. Importantly, differences in index values that were due to the choice of the method were not biased, i.e. the index values were not systematically shifted in a certain direction. While patterns of spatial differentiation of indices were largely unaffected, method selection affected the result at smaller scales. This indicates that at large

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[1] Although the site Randu meadows is located at the Baltic Sea the climate there is continental. In particular the winters are cold, as the influence of the Gulf Stream is small compared to the Western European coastal regions. On the other hand, winters in the Rhine-Main-Observatory are mild, which is a characteristic feature of the oceanic climate. Plant communities which show a high mean oceanity are adapted to cooler summers and milder winters. In contrast, high continentality means that plant communities consist of species that are adapted to higher temperature amplitudes between (hot) summers and (cold) winters. The oceanity/ continentality gradient also reflects changing precipitation patterns. Higher oceanity is associated with higher precipitation. This explains the index values at the site Zöbelboden which is characterized by high precipitation.

indices are determined mainly by the species pool while at small scales species abundance becomes more important.

Generally speaking, the eLTER virtual access scheme provides high quality vegetation data that can be used for analyses without major adjustments. To facilitate their use it would be helpful if they could be linked to a synonym data base to overcome the problem of different taxonomies. To increase clarity, various parameters should not be stored in common tables.

5 Outlook

The present work shows that the new indices reflect the composition of plant communities with respect to climatic niches. Thus they have a high potential to be used as indicators to detect climate change impacts on biodiversity. However, the low number of test sites and time series represents a clear limitation which makes general statements difficult. Future work should therefore focus to increase the number of sites and data sets to cover larger climatic gradients and different habitats. In particular longer time series need to be included. Once the number of datasets has increased index values should be related to climatic parameters to better interpret patterns of variation.

Acknowledgements

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