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Interactions among ecosystem services across Europe: Bagplots and cumulative correlation coefficients reveal synergies, trade-offs, and regional patterns

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ABSTRACT

Understanding interactions of ecosystem service pairs and bundles is vital for making reasonable decisions in ecosystem management. Often, interaction analyses use linear correlation coefficients in order to identify trade-offs and synergies. Due to non-linear relations between ecosystem services in many cases, only weak interdependencies are revealed by this approach. For this reason we adopted nonparametric statistics, specifically bagplots (bivariate boxplots), for analyzing ecosystem service interactions. We demonstrate that bagplots complement correlation coefficients in assessing ecosystem services at NUTS 3 level across Europe and use them for mapping geographical patterns. In addition we suggest a new measure, which is the cumulative correlation coefficient *R* to rank the ecosystem services based on their synergies and trade-offs. We found that crop capacity is clearly the most conflicting ecosystem service, and carbon storage the one with the highest synergistic value. We conclude that bagplots allow insights into the relationships between ecosystems services beyond the highly aggregated correlation coefficients. In addition the new standardized measure – cumulative *R* – could support monitoring of trade-offs and synergies in time for a given study region or comparing study regions with respect to their frictions in ecosystem services supply.

1. Introduction

Ecosystem services are the aspects of ecosystems utilized (actively or passively) for human wellbeing (Fisher et al., 2009). Hence, ecosystem services can comprise ecosystem functions, processes and structures, as long as they contribute to human wellbeing. Since human societies evolved, ecosystem services have been an inherent part of the relationship between humanity and nature. Human wellbeing has always been dependent on ecosystems which not only provide food and timber but also regulate water and air quality (Ehrlich and Ehrlich, 1992). However, researchers have only intensively investigated this field for the past two decades (Fisher et al., 2009). The growing scientific interest might not be surprising in light of the increasing exploitation of natural resources, especially as anthropogenic intervention in natural stocks and processes causes severe stress on ecosystems and the services they provide (Koellner, 2011). Consequently, decisions made by governments and businesses regarding the utilization of natural resources and processes, either intentionally or not, affect ecosystem services.

According to the millennium ecosystem assessment (MA) (United Nations, 2005), over the past 50 years, provisioning services regarding food production increased globally while other services decreased. The MA also asserts that worldwide 60% of all ecosystems are in a state of degradation. Although the MA provides vital data and knowledge about ecosystem services, most services were investigated individually and without considering more than two services at a time (Bennett et al., 2009). Finally induced by the MA and facilitated by the provided data, more and more scientists investigate the interactions of ecosystem services and ecosystem service bundles (Rodriguez et al., 2006). This is particularly important because conflicts in ecosystem services as well as biodiversity can increase due to global climate change, but also due to resource needs of a growing world population. This trend asks

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for credible and transparent ecosystem management strategies (Daily et al., 2011). However, in most cases environment and resource management strategies were driven by approaches addressing single factors or single objectives, while a range of other factors were not taken into account (Tillis and Polasky, 2011). For instance, strategies aimed at an increasing industrial production often operate at the expense of air quality, water quality and human well-being; if deforestation serves the purpose of increased crop production, a provisioning service is generated but at the same time, regulating services (e.g., erosion control, climate regulation, soil fertility) formerly provided by the forest will at the very least be diminished. Besides this scenario of interaction, in many cases there does not yet exist such clear understanding of the mechanisms behind synergies and trade-offs among ecosystem services. Especially for decision-makers consequences associated with interactions are often not visible enough to make balanced decisions (Tillis and Polasky, 2011).

The ecosystem service approach allows decision-makers to decide on environmental issues in a more informed but also more challenging way. Additionally it is a tool to express the vital importance of intact environmental systems to societies (Levine and Chan, 2011). To consistently apply this tool in practice, it is necessary to understand the mechanisms that occur regarding ecosystem services and the interactions among them. In this context, trade-off analysis is useful to investigate ecosystem service interactions. Trade-offs occur when the provision of one ecosystem service is elevated at the expense of another service. Trade-offs are induced by anthropogenic management decisions either intentionally or without the awareness of their occurrence (Rodriguez et al., 2006). Consequently, synergies between ecosystem services happen when the elevation of one service causes an increase in another service. In the recent past, trade-off analysis became a major field in ecosystem service studies. These trade-offs and synergies are either a simultaneous response to an external driver or a true interaction between two ecosystem services (Bennett et al., 2009). To provide a brief overview of the commonly applied methodology and the results obtained we summarize four studies that deal with trade-off analysis.

In South Africa, Egoh et al. (2008) assessed the relationships between five ecosystem services. In 15 cases they obtained significant linear correlations, of which 10 were weakly correlated ($r < \pm 0.3$). Primary production was positively associated with four services: surface water supply, water flow regulation, soil accumulation and soil retention. Chan et al. (2006) investigated the dependency among six ecosystem services in the Central Coast ecoregion of California, USA. In this study, Pearson coefficients were computed to indicate correlation of ecosystem service pairs. The results gave only weak correlation coefficients for all 21 pairs ($r < \pm 0.3$) except for carbon storage and water storage ($r = 0.58$). They also reported a rather strong relation between soil retention and soil accumulation. Raudsepp-Hearne et al. (2010) tested interactions of 12 ecosystem services in a mixed-use landscape in Quebec, Canada. Again, linear correlation analysis was conducted in order to explore ecosystem service trade-offs. Of 34 pairs, 8 were highly correlated ($r > \pm 0.5$), 16 moderately correlated ($r > \pm 0.3$ and $< \pm 0.5$) and 10 weakly correlated. They identified trade-offs between provisioning services and both cultural and regulating services. A trend was particularly clear for the provisioning service crop production: it showed negative interaction with nine other services and a positive relation to pork production. Crop and pork production were negatively correlated with all regulating services. Ecosystem service bundles were spatially investigated within this study. Raudsepp-Hearne et al. (2010) identified six types of bundles that were linked to specific areas in the landscape. Beier et al. (2008) conducted trade-off analyses in southeast Alaska, again correlation analyses were carried out to test 18 pairs of indicators for interactions. The obtained linear correlation coefficients indicated only weak relations among the indicators.

The four studies summarized above reflect common methodology in trade-off analyses. The assumption in all four studies is the existence of a linear relationship between ecosystem services. In contrast Koch et al. (2009) demonstrated that ecosystem services do, due to their natural variation in space and time, not interacting linearly. Ruijs et al. (2013) took non-linearity into account for trade-off analyses. In this context it is further suggested to apply methods from external fields (e.g., quantile regression from econometrics) to analyze ecological data (Cade and Noon, 2003).

In this paper we first concentrate on an approach that allows us to investigate interactions among different services beyond simple linear correlations. The data in our study were derived from an assessment of ecosystem services across Europe (Maes et al., 2011, 2012). They used principal component analysis and multinomial logistic regression to assess the interactions of ecosystem services. In this paper we want to complement their parametric statistics approach by using bagplots, i.e., bivariate boxplots well known in nonparametric statistics, to depict typical relations among pairs of ecosystem services (Rousseeuw et al., 1999; Hyndman and Shang, 2010). These allow operationalization of the possibility space as well as the trade-off evaluation space (in sensu Paracchini et al., 2011) for specific ecosystem services. Secondly, we use the cumulative correlation coefficient R as a new index to rank ecosystem services given their potential for synergies or trade-offs with all other services in the correlation matrix. Thirdly, we map the ecosystem service interactions on the level of NUTS regions.

2. Materials and methods

2.1. Data

The data we used for the analyses was derived from a former study: “a European assessment of the provision of ecosystem services” (Maes et al., 2011). The given data set contains spatial indicators for a total of ten ecosystem services at European Union (EU) scale (Table 1). The geocode standard NUTS (nomenclature of territorial units), established by Eurostat, was used for spatial mapping of the ecosystem service indicators. Data were available at the NUTS 3 level for all EU member states except for Belgium, Germany and the Netherlands. For these three countries the data were compiled at NUTS 2 level because their NUTS 3 regions are much smaller compared to the other EU countries. Using a combination of these two codes, a total of 847 polygons within the EU were established. For each polygon data were obtained for all indicators.

2.2. Methods

Graphical and correlation analyses were performed to investigate and characterize interactions among ecosystem services (ES). For graphical analysis we used bagplots (Rousseeuw et al., 1999). The bagplot is a bivariate version of the boxplot (Tukey, 1975) consisting of a point marking the highest half-space depth, which is labeled depth median (Tukey, 1977); see Chakraborty and Chaudhuri (2006) for the statistical definition of half-space depth, surrounded by a region (bag) displaying the location of 50% of the data points (see Fig. 1). The bag is surrounded by a further area called a loop. The loop is narrowed by a fence, which is calculated, as recommended by Rousseeuw et al. (1999), by bloating the bag by a factor of three. All data points outside the fence are outliers. Similar to univariate boxplots the bivariate bagplots can also be visually interpreted. Important features for general explanation of the data distribution are: the position of depth median, dispersion