WEALTH OF NATIONS AND WEALTH OF NATURE:

WHAT IS THE RELATIONSHIP BETWEEN BIODIVERSITY, ECONOMIC WEALTH, AND INDIVIDUAL WELL-BEING?

ANJA ZIRNGIBL, HENRIK VON WEHRDEN, DAVID ABSON AND STEFAN BAUMGÄRTNER

Leuphana University of Lüneburg, Germany

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Abstract: This study analyses the relationship between biodiversity, economic wealth, and individual well-being. It seeks to contribute to quantification of biodiversity's role for human well-being and the contribution of human activities to biodiversity loss.

The hypotheses are 1) a positive relationship between biodiversity and well-being, because via securing ecosystem functioning, biodiversity renders ecosystem services that contribute to human well-being. 2) The relationship between biodiversity and economic wealth is negative because economic activities are drivers of biodiversity loss.

We analysed proxies representing biodiversity, economic wealth, and well-being - namely bird species diversity, GDP per capita and individuals' life satisfaction - using multivariate statistics and generalized linear models. Results show that 1), biodiversity positively correlates with well-being 2), biodiversity negatively correlates with GDP per capita. 3), interaction between birds and education correlates positively with economic wealth.

This study confirms a positive correlation between human well-being and economic wealth, while the relationship between human well-being and biodiversity is influenced by economic wealth. Interpretation of causal relationships is difficult, yet increased well-being in low-income countries with high biodiversity might be interpreted as more intact socio-economic livelihoods. Data shows trade-offs between biodiversity conservation and economic wealth that could potentially be overcome via improving education.

1   Introduction and State of Research

The relationship between biodiversity, economic wealth, and individual well-being has increasingly come into the focus of the scientific community. Being happy and satisfied with one's life is considered an ultimate goal of human mankind (Frey and Stutzer, 2002). Consequently, identifying its determinants has always been an important subject to scientific research. At least since Adam Smith's *Wealth of Nations*, economists have associated human well-being with economic wealth (Diener and Diener, 1995, p. 275). Economic wealth is supposed to improve our quality of life. Despite criticism from scholars (Diener and Oishi, 2003), most societies still aspire to increase economic wealth in order to enhance well-being (Diener and Diener, 1995).

In the last years, however, activities that increase economic wealth have been identified as one key driver associated with the dramatic loss in biodiversity (Butchart et al., 2010; ME Assessment, 2005; Rockström et al., 2009a, 2009b; Wilson, 2010). We currently face the "Environmentalist's paradox" where many ecosystem services are degrading, while well-being is increasing (Raudsepp-Hearne et al., 2010). To meet our growing demand for food and commodities, the demand for natural resources such as fresh water, timber, fuel and land has increased exponentially. This has lead to the degradation of ecosystems and to the reduction of biological diversity on Earth (ME Assessment, 2005, p. 1)[1]. Consequently, increases in economic wealth can severely contribute to the loss in biodiversity, while enhancing well-being at the same time.

The relationship between biodiversity, economic wealth, and individual well-being is part of many complex interactions in the human-nature system. The Millennium Ecosystem Assessment (ME) initially summarized the benefits that people obtain from ecosystems. Thereby, it contributed to a better understanding of the role of biodiversity for human well-being. Biodiversity is important "for sustaining ecosystem functioning and services" (Rockström et al., 2009b, p. 14). Ecosystems, in turn, provide different regulating, provisioning and cultural services that contribute to human well-being, e.g. access to resources, food and shelter (Daly and Farley, 2004; Dasgupta, 2001; ME Assessment, 2005). Additionally, human interactions with nature are considered important contributors to well-being (Stiglitz et al., 2010, p. 81ff; UNU-IHDP, 2012).

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[1] For further discussions of population growth and other drivers of biodiversity loss, see Palmer and Di Falco (2012), Swanson (1995) and Swanson & Groom (2012)

1.1　Research on biodiversity and economic wealth

To date, research on the relationship between biodiversity and economic wealth has focused on i) the impact of economic wealth, measured as increasing income per capita, on environmental degradation such as biodiversity loss (Asafu-Adjaye, 2003; Dietz and Adger, 2003; McPherson and Nieswiadomy, 2005) and ii) on how the value of biodiversity can be assessed and integrated into decision-making (Daly and Farley, 2004; Freeman, 1993). According to Freeman (1993), renewable natural resources "are valuable assets in that they yield flows of services to people" (Freeman, 1993, p. 2). Biodiversity is a form of renewable natural resource and, if commercially exploitable (e.g. forests and fisheries), can contribute to economic wealth. Due to "externalities and the common property and public good character" (Freeman, 1993, p. 2) however, the true and entire social value of these resources is not captured by the market and therefore not integrated into decision-making processes (Dasgupta, 2001; Freeman, 1993, p. 107).

The effect of income increases on biodiversity has been analysed by Asafu-Adjaye (2003). The study focuses on the relationship between the occurrence of different species types and GDP (gross domestic product) per capita. Results indicate an adverse effect of economic wealth on biodiversity. According to Asafu-Adjaye, the increasing rate of habitat conversion in developing economies to produce material goods and services results in higher biodiversity losses (2003, p. 177). In addition, the composition of the economic output of a country, measured by the agricultural value, contributes to biodiversity losses, especially in low-income countries.

An econometric model that includes a couple of socioeconomic, demographic and environmental aspects was estimated. For example, data on population density, a dummy for climate and the black market premium on foreign exchange as a proxy for exchange rate and trade policies were used (Asafu-Adjaye, 2003, p. 177f). Asafu-Adjaye hypothesizes that the development of a country is accompanied by the formation of economic, social and political institutions. These "help internalize the value of biodiversity into decision-making processes of the state and individuals" (2003, p. 177) and thereby enhance environmental quality and biodiversity.

Asafu-Adjaye (2003) related the study to the environmental Kuznets curve (EKC) hypothesis[2]. The EKC represents an inverted u-shaped relationship between environmental degradation and economic wealth. As income increases, the pressure on the environment increases. After a certain threshold value it starts to decrease. Hence, countries reduce their environmental quality in the first stages of economic growth, while

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[2] For a review see Dinda (2004).

improving it later after initial development. Dietz and Adger (2003), Holland et al. (2009), and McPherson and Nieswiadomy (2005) revealed a range of factors influencing biodiversity, such as population density, an island dummy variable, income inequality, percentage of endemic species, forest area, number of demonstrations as a proxy for political stability, the Freedom House democracy index. Dietz & Adger (2003) find no EKC for species richness, whereas McPherson & Nieswiadomy's (2005) supported the EKC curve. According to their study, the percentage of threatened species rises with increasing income levels up to around $10,000 to $15,000 and then falls (2005, p. 405).

1.2 Research on biodiversity and well-being

First attempts to analyse the relationship between biodiversity and well-being have been made with data on life satisfaction as a proxy for well-being (Rehdanz, 2007). Many scholars have recognized the key role of biodiversity for human well-being (Atkinson, G. et al., 1997; Daly and Farley, 2004; Dasgupta, 2001). Biodiversity provides numerous regulating, provisioning and cultural ecosystem services (ME Assessment, 2005) and is therefore essential for human well-being.

In the past decade, welfare economics engaged in quantitative analyses of the relationship between biodiversity and well-being, using data on life satisfaction as a proxy. Various correlates of well-being have already been identified, such as income, freedom, marriage, environmental conditions (Dolan et al., 2008; Frey and Stutzer, 2005, 2002; Silva et al., 2012; Zidanšek, 2007) and climate variables (Rehdanz and Maddison, 2005).

Rehdanz (2007) revealed a significant relationship between the number of existent and threatened species and life satisfaction. Rehdanz (2007) calculated an econometric model using maximum likelihood techniques thereby controlling for spatial correlation. Data on life satisfaction for 81 countries was obtained from the 1999/2000 World Value Survey, measured on an ordinal scale of 0-10. Independent variables for species diversity were taken from the World Resources Database from 2004 and 2006. In addition obtained Rehdanz (2007, p. 4) data on GDP per capita, the percentage of the population over 65 years and life expectancy from the World Resources Database, inflation rates and annual growth rates from the World Development Indicators 2001 and temperature as well as precipitation records from her own previous study (Rehdanz and Maddison, 2005). Because the World Value Survey 1999/2000 is limited to 81 countries, the sample size is significantly reduced.

In order to understand the complex interactions in the human-nature system and the role of biodiversity for well-being and economic wealth, we analysed the two relationships: between biodiversity and well-being and between biodiversity and economic wealth.

We build models out of an extensive set of proxies for well-being and economic wealth models on a country scale. We used number of birds species per log transformed square kilometre (km²) as a proxy for biodiversity. Economic wealth was operationalized with data on the GDP per capita, while well-being was approximated by the results of the Gallup World Poll survey on individual life satisfaction.

By examining both the relationship between biodiversity and well-being, as well as biodiversity and economic wealth, we indirectly examine the relation between economic wealth and well-being.

Furthermore, this study corrects for socioeconomic, demographic and environmental factors that influence the human-nature relationship. In order to obtain a homogenous grouping of the dataset, income categories will be formed. Using univariate statistical approaches, including tree models and the cluster analyses, the grouping in this study is based on formal analyses, and not on subjective criteria as used by previous studies.

We attempt to overcome previous shortcomings of small simple sizes in the case of data on life satisfaction by using data from the World Gallup 2012 that covers 151 countries. The dataset at hand is therefore not only bigger but also more up-to-date. After intensive research a higher number of explanatory variables that describe other social, economic, demographic and environmental determinants can be included. Therefore, we expect the analysis of the relationship between biodiversity and well-being to be more comprehensive than in previous studies.

Due to the interdisciplinary nature linking economics and ecology we build on a wide array of assumptions. We combined different methodological approaches rooted in both disciplines. Building on previously known relationships between biodiversity, economic wealth and well-being, we hypothesise that:

1) The relationship between biodiversity and well-being is positive indirectly indicating the benefits people obtain from biodiversity and ecosystem services.

2) The relationship between biodiversity and economic wealth is negative because economic activities contribute to biodiversity loss.

2   Data

Indirect proxies for biodiversity, economic wealth, and well-being were obtained in order to analyse the relationships between them. As these terms are vague and often used in different context, this section elucidates how they are interpreted and operationalized in this this study. It further describes the different datasets. Every variable is assigned to a list of countries that was chosen from the World Bank format that covers 214 nations. Due to missing values in the data sets however, the number of countries included in the analysis depends on the variables employed in each model.

Appendix 1 provides the characteristics of each variable, including the sample size, the source and the processing of the data and appendix 2 includes the descriptive statistics.

2.1   Biodiversity

In this study we used the number of bird species per country as an indicator for biodiversity, because birds are the best-studied vertebrate group (Rodrigues, 2006, p. 1051) and as a result, reliable data is available for many countries. Data on the number of bird species [Birds] from the BirdLife International website (BirdLife International, 2013). As area size is one important determinant for biodiversity[3], the number of bird species is standardized per country area. This way, countries with different sizes are comparable. However, if standardized per surface area [Area], very small countries and islands seem to have a high biodiversity in comparison to countries with more surface area. We therefore log transformed km[2] following the standard assumption for MacArthus & Wilson on island biodiversity (MacArthur and Wilson, 1963).

2.2   Economic wealth

In this study, we chose to operationalize economic wealth with data on the gross domestic product (GDP) per capita. GDP is an economic flow, which "measures the total income of everyone in the economy" (Mankiw, 2008, p. 492) in one year. GDP per capita reflects, on average, the income of an individual living in the respective country.

We chose the GDP as an indicator for economic wealth for several reasons:

First, "it is thought to be the best single measure of a society's economic well-being" (Mankiw, 2008, p. 492) and an important indicator for long-term economic development (UNU-IHDP, 2012, p. 167). For these reasons, nearly all countries on Earth collect data on the GDP, which makes it, second, a widely available measurement for the average wealth of a nation's population. Third, the data is globally comparable because of the consistency

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[3] The species-area relationship is one model to explain biodiversity: $S=CA^z$ (Rosenzweig, 2003), where the size of the habitat area (A), a constant (C) and an exponent (z) (representative for the specific sort of ecosystem (Baumgärtner, 2007, p. 8)) determine the species diversity in a specific area.

in collection methods. And fourth, GDP per capita is frequently used in statistical analyses for the above named reasons. Consequently, the results of this study can be compared to the findings from other studies.

As a shortcoming, the GDP does not reflect changes in the underlying capital stock, which is also an important indicator for a nation's economic wealth. In contrary to GDP per capita, data on capital stocks is difficult to obtain on a global level because few governments collect that data (UNU-IHDP, 2012, p. 28). Availability is often limited to a small selection of countries, mainly from the EU and the OECD and is thus not very useful in a global analysis. Some governments provide their own data, but due to different sampling methods most of the data is not useful for comparison (UNU-IHDP, 2012, p. 28). We obtained data on private worth per capita, net foreign assets per capita and produced capital per capita only. These variables were used for the first analysis steps. Since little information on the collection of the data is available and the data processing steps showed significant correlations with the GDP per capita, GDP per capita remained the best available variable representing economic wealth.

Data was obtained from the World Bank Website (World Bank, 2013a) for the years 2005-2011 in purchasing power parity rates in international US$, to account for price levels. We calculated the average of seven years to balance economic fluctuations. Most of the low-income countries are located in Sub-Saharan Africa and Asia. Most Latin American countries have GDP per capita between the lowest and second lowest income category. Overall, the closer a country is located to the equator, the lower its income. High-income countries are mainly located in the northern hemisphere. The USA, Liechtenstein, Norway, and, as a geographical outlier, the United Arab Emirates have the highest GDPs per capita. European countries, Canada, and Australia follow with a GDP per capita between 30,000 and 45,000 US$ (PPP).

2.3   Well-being

Individual well-being is a concept that reflects how happy and satisfied people are with their lives. In other words, life satisfaction is a key component of individual well-being (Diener and Oishi, 2003, p. 186). For this reason, this study operationalizes well-being with data on life satisfaction. Life satisfaction is the output of a subjective measurement where individuals evaluate their life satisfaction. The term "*individual well-being*" was chosen for this thesis' title to reflect the subjectivity of the data basis. However, for simplification, only the term *"well-being"* will be used from now on.

One aim of this study is to analyse the relationship between biodiversity and well-being on a country basis. For this reason, data that reflects a nation's level of well-being is required for as many countries as possible.

Data on life satisfaction fulfils this requirement because it is "the most widely available subjective well-being measure across cultures" (Diener and Oishi, 2003, p. 186). Data collection methods have been improved in the last years, now making it possible to compare people's life satisfaction across many nations. "With […] several questions on global self-reports, it is possible to get indications of individuals' evaluation of their life satisfaction" (Frey and Stutzer, 2002, p. 2). Though this data is subjective, it has been argued that it is valid and useful for formal analyses (Di Tella et al., 2003, in Rehdanz, 2007). As availability on a country-level and robustness of data are decisive for this study, life satisfaction is also a reasonable variable for the operationalization of well-being from a statistical point of view.

The dataset life satisfaction [LifeSat] was obtained from the Gallup World Poll survey from 2007-2011 and was taken from the Human Development Report 2013 (UNDP, 2013a). The Gallup World Poll is a social survey that reflects individuals' evaluation of their life satisfaction. In 150 countries, a representative share of the population answers the question:

> *"Please imagine a ladder, with steps numbered from zero at the bottom to ten at the top. Suppose we say that the top of the ladder represents the best possible life for you, and the bottom of the ladder represents the worst possible life for you. On which step of the ladder would you say you personally feel you stand at this time, assuming that the higher the step the better you feel about your life, and the lower the step the worse you feel about it? Which step comes closest to the way you feel?"* (UNDP, 2013a).

According to the Gallup WorldView, the "survey data are representative of 95% of the world's adult population" (Gallup WorldView, 2013). In order to assure this, samples are probability based, and the target population is the entire civil population starting with the age of 15. The questionnaire contains the same standard set of core questions around the world and is translated into the major languages of each country. A typical World Poll survey includes at least 1,000 individuals (Gallup WorldView, 2013). Countries with the highest life satisfaction, between 7.1 and 7.8, are located in North America, Oceania, Middle America, and northern and central Europe. Exceptions are the United Arab Emirates and Israel. Most of the Latin American countries follow with values between 6.1 and 7.0 and, only some, between 5.1 and 6.0. Countries with very low life satisfaction values are mainly African countries, such as the Democratic Republic of Congo, Chad, and Botswana.

2.4 Confounding factors

Other aspects that influence the relationship between biodiversity, economic wealth and well-being must be included into the analysis. These confounding factors were operationalized by the following data.

Abiotic factors

This category contains environmental determinants that reflect climatic conditions: mean annual precipitation [Prec], precipitation seasonality [PrecSeas], mean annual temperature [Temp] and temperature range [TempRange] (WorldClim, 2013). Area size is already accounted for in the standardization of the species numbers.

Biotic factors

As confounding factors that represent the biota of a country[4], data on biocapacity [Biocap] (WWF, 2012), mean net primary productivity [NPP] (Imhoff et al., 2004), forest cover [ForCov] (FAO, 2013) and protected areas [ProtArea] (World Bank, 2013a) was collected and integrated into the model.

The measurement of natural capital or ecosystem services is difficult so far (Dasgupta, 2001; UNU-IHDP, 2012) and therefore only little current data is available .

Economic factors

The GDP is also used as a confounding factor in the model for well-being. Further flow variables are GDP growth [GDPgro], adjusted net savings[5] [ANS], and the agricultural share of the economic output as percentage of the GDP [Agr] (World Bank, 2013a). All were obtained from the World Bank Website (World Bank, 2013a). Again, we used the average of seven successive years (2005-2011) to balance economic fluctuations.

Also, economic stock variables were used as confounding factors. Private worth per adult [PrivWorth] measured as purchasing power parity rates in US$ was obtained from the UN University – World Institute for Development and Economic Research (UNU-WIDER, 2013). Data on produced capital per capita [ProdCap] comes from the (World Bank, 2013c). Furthermore, net foreign assets per capita [NFA], that is "the sum of foreign assets held by monetary authorities and deposit money bankers, less their foreign liabilities" (World Bank, 2013a), was included to reflect the indebtedness of a nation.

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[4] For more information about the data see chapter 3.1.
[5] "Adjusted net savings are equal to net national savings plus education expenditures and minus energy depletion, mineral depletion, net forest depletion, and carbon dioxide" (World Bank, 2013b).

Socioeconomic and demographic factors

Socioeconomic data reflect the societal and institutional framework for the economy of a nation. For example, the Democracy Index [Democ] from The Economist (The Economist, 2013) aggregates information on the electoral process and pluralism, the functioning of government and political participation, the political culture and civil liberties of each country. Similarly, the Index of Economic Freedom [EconFree] is a composition of different institutional preconditions such as property rights, freedom from corruption, government spending, and fiscal, business, labour, monetary, trade and investment freedom (The Heritage Foundation, 2013). The Index of Globalization [Glob] contains data on economic flows, economic restrictions, information flows, personal contact and cultural proximity (KOF, ETH Zürich, 2010). Furthermore, the number of mean years of schooling [Edu] was included as a proxy for education from the Human Development Report (HDR) (UNDP, 2013b). The Gini Index [Gini] is a measurement for income inequality, that means the distribution of income among individuals of one economy (World Bank, 2013a). Additionally, the variable infrastructure [Infra] was included, measured as the road network in km^2 and standardized it per land area of a country. Combined with education, this could be a proxy for the technological level. Unemployment [Unempl] is the last explanatory variable in this category, also obtained from the (World Bank, 2013a).

Sociodemographic data include life expectancy [LifeExp] (UNDP, 2013a) and the percentage of the population above 65 years [Pop65] (World Bank, 2013a). The variable population density [PopDens] was obtained by dividing the population (UN Statistics Division, 2013) by the land area of a country. Since economic data is standardized per capita and biodiversity data is standardized per log transformed country area, it is important to control for population density.

 Urbanization [Urb] reflects the percentage of the total population living in urban areas (World Bank, 2013a).

Subsoil assets

The variable subsoil assets [Subs] includes non-renewable resources such as fossil fuels and minerals and is considered to affect the economic wealth of a country (World Bank, 2013c).

3 Models

To analyse the relationship between biodiversity and well-being, and the relationship between biodiversity and economic wealth, two models were developed. Many other factors influence the complex relationships, such as socioeconomic and demographic aspects, biotic and abiotic factors. Consequently, these aspects must be included in the model as confounding factors.

3.1 Biodiversity and well-being

The first model contained well-being, measured via self-reported life satisfaction, as a response variable. Confounding factors were socioeconomic factors, that include education, unemployment and infrastructure, and the Gini Index representing income distribution. Life expectancy, population density, the percentage of the population over 65 years, and the share of the population living in urbanized areas are demographic factors. Economic freedom, globalization and democracy represent the political surrounding. Frey & Stutzer also found out that in Germany, marriage and life satisfaction are related: "as the year of marriage approaches, people report, on average, higher satisfaction scores. In contrast, after marriage, the average reported satisfaction with life decreases" (Frey and Stutzer, 2003, p. 19). Due to a lack of data for marriage rates on a global level, this variable cannot be included in the analysis.

Aspects of nature are represented with three different types of variables. First, the numbers of recorded bird, animal and plant species represent biodiversity in the narrow sense (see chapter 3.1). Biotic factors such as the net primary productivity of a country, forest cover, biocapacity or the percentage of protected areas can indirectly reflect biodiversity and confound the relationship between biodiversity, economic wealth, and well-being. Both groups, species diversity and biotic factors, are strongly determined by abiotic factors. Abiotic factors could indirectly affect well-being, for example via biodiversity. Consequently, they must be included in the model as confounding variables. The specification of the theoretical model is[6]:

$$\text{LifeSat} = \alpha_1 \text{ x Econ} + \alpha_2 \text{ x Social} + \alpha_3 \text{ x Species} + \alpha_4 \text{ x Abiotic} + \alpha_5 \text{ x Biotic} + \varepsilon$$

3.2 Biodiversity and economic wealth

Surveys on economic growth (Aghion and Howitt, 2009; Mankiw et al., 1995; Rogers, 2003) were considered in order to identify factors that could influence economic wealth. For example, population density and urbanization are variables representative for labour effectiveness, which affects economic growth. To represent capital accumulation and

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[6] This model includes the variable groups from which different factors will be tested.

investments, stock variables such as private worth, produced capital and net foreign assets were included to explain economic wealth. Furthermore, education and infrastructure, measured as total road network in km, are expected to influence economic wealth.

Indicators of the *resource curse,* also known as the *Dutch disease,* describe the phenomenon that the endowment with non-renewable resources (that is, fossil fuels and minerals) hinders economic growth. "Countries that are rich in oil, minerals, and other [non-renewable] natural resources, economic growth over the long haul tends to be slower than in other countries that are less well endowed" (Gylfason, 2001, p. 848). They found out that institutional quality is positively linked to economic growth and the efficient use of natural resources. Following these findings, factors such as globalization, democracy and economic freedom were introduced to the model as confounding factors.

Further confounding factors are climatic circumstances, reflected via temperature, temperature range, precipitation and precipitation seasonality directly. Following Gylfason (2001), we controlled for education.

As for well-being, the different factors representing biodiversity will be included in the model: species diversity, biotic factors, and abiotic factors as environmental determinants. With the inclusion of all these different aspects, the theoretical model is:

$$\text{EconWealth} = \beta_1 \text{ x Social} + \beta_2 \text{ x Econ(Stocks)} + \beta_3 \text{ x Species} + \beta_4 \text{ x Abiotic} + \beta_5 \text{ x Biotic} + \varepsilon$$

The theoretical models represent the conceptual basis for the calculation of the generalized linear models (GLMs).

4   Methods

The following section describes the methods used in this study. It explains the different steps to explore the dataset and the correlations among the variables, and to cluster it. It then elucidates the statistical methods that were applied to test the hypotheses. All calculations and figures were made with the software R.

4.1   Data processing

Data was initially inspected using histograms to check for data distribution, A Spearman correlation matrix of all variables was generated. Correlation categories for weak, medium and strong correlation were established and highlighted in different colours for a better overview. The correlations among one variable group address the issue of multicollinearity: variables that are strongly correlated with each other would inflate a model if used simultaneously. Inflation means that the significance of one factor becomes misleadingly high and hence not reflects its real impact on the dependent variable.

To further inspect the structure of the different groups and to identify the most important variables in each group, Principal Component Analysis (PCA) was conducted. The aim of a PCA "is to reduce the dimensionality of a data set consisting of a large number of interrelated variables" (Jolliffe, 2002, p. 1). A PCA is able to identify 1) the variables that represent most of the variability in the data group and 2) the variables that are similar to each other and could therefore be subject to multicollinearity. The result is a set of variables that had priority in the model testing.

To detect whether there are homogenous groups – for example income groups - in the data set, two different clustering methods were applied: The tree function (R Package tree) was used to cluster the dataset according to the variance in the variables GDP per capita and birds. By applying the cluster analysis method (R Package cluster, agnes method=ward), the analysis of the variance of more than two variables was possible. Nearly all variables were included, except the Gini Index because of the small sample. Therefore, this clustering method is more complete than the tree model.

The data processing steps structured the data and identified the most important components that will be used for further analysis. This is especially important for the calculation of GLMs. Understanding the principal relationships in the data set helps to avoid statistical sources of errors such as multicollinearity.

Furthermore, the PCA axes of the different groups contain most of the information of the dataset and can be used as variables representing the respective group. GLMs were also calculated with the first two PCA axes as non-redundant main components of the data.

4.2   Relationship patterns with generalized linear models

Multiple variables influence the relationship between biodiversity, economic wealth, and well-being. Generalized linear models (GLMs) allow for the analysis of correlations while testing for confounding factors. GLMs cover a range of regression methods, and other than normal distribution are also implemented (Dobson, 2002, p. 4). Variables representing economic wealth, for example GDP per capita, show a Poisson distribution. Via a link function, GLMs allow application of Poisson regression to such dependent variables. Since life satisfaction is normally distributed, we applied an ordinary-least squares for this variable. With the specification of the distribution family (in this study either either Poisson or gaussian), GLMs cover both methods.

The calculation of GLMs started with the variables that were identified as the most important components. More variables were included stepwise and numerous different variable combinations were tried out. After forward selection of variables I used backward selection with the stepwise reduction function and obtained combinations with significant variables for each model. The calculation of the variance inflation factor (VIF) (R package cars) helped to identify and exclude variables that are subject to multicollinearity and inflate a model. Following the rule of thumb all variables with a VIF higher than five were excluded from the model.

5   Results

GLMs indicate 1) a significant positive correlation between biodiversity and well-being in low-income countries and 2) a significant negative correlation between biodiversity and economic wealth among the whole dataset. Another result is 3) that the interaction of biodiversity and education correlates positively with economic wealth, especially significant in high-income countries.

The different cluster groups, dividing the data set into low- and high-income countries, show significant differences in biodiversity.

5.1   Data processing

5.1.1   Correlation matrix and principle component analysis

The correlation matrix (see table 1) displays all linear correlations within the dataset.

Correlations in the groups

Some of the variables representing species diversity and biotic factors strongly correlate with each other. For example, the number of animal species correlates with the number of both bird and plant species with values between 0.7 and 0.9. Therefore, they are highlighted yellow in the table in annex 3. The PCA shows a strong loading for the variable animals on the first axis. However, since the variable bird species is especially representative for biodiversity, it will be used for further analysis. Among the **biotic factors,** forest cover is the strongest loaded variable and therefore representative for this data group. Among the **abiotic factors**, precipitation and temperature are correlated with temperature range. These climatic variables are likely to be related to each other. Consequently, they should not be used simultaneously in one model. The PCA indicates a strong loading for temperature range on the first axis and for precipitation seasonality on the second axis (vertical). These two variables are important for further analysis. The next group contains **economic factors.** Many variables are strongly correlated in this data group, especially GDP per capita with private worth and produced capital.

The variables agriculture and net foreign assets negatively correlate with GDP per capita.

Again, the PCA filters the most important variables of this group. These are net foreign assets and GDP.

Variables representing **socioeconomic and demographic factors** strongly correlate with each other. The variable globalization is correlated with education, economic freedom, and further with life expectancy, democracy, population over 65 and urbanization. Population over 65 correlates strongly with education and with life expectancy. The PCA identifies population density and life expectancy as most important variables. However, life

expectancy can be interchanged with economic freedom or globalization, because these are strongly correlated. Furthermore, population density can be replaced by unemployment, and the related variables can be used interchangeably in a model to find out which one has the best explanatory power.

According to the PCAs, the following table the most important variables of the data set.

Table 1: Variables reflecting most of the variance in their group, according to the PCAs. Variables with "//" can be replaced by the following variable.

Abiotic factors	Biotic factors	Economic factors	Socioeconomic and demographic factors
Precipitation seasonality	Forest cover	GDP// Produced capital// Private worth	Population density// Unemployment
Temperature range		Net foreign assets	Life expectancy// Economic freedom// Globalization

Interactions between different groups

In this section, correlations between the different data groups will be analysed. Variables that represent species diversity and biotic factors correlate weakly with variables that represent economic factors. Species diversity and biotic factors were not significantly related to economic proxies. The only relationships are mostly negative and rather weak, for example the standardized number of bird species correlates negatively with GDP per capita (-0.3). Equally, the variables bird, animal and plant species are negatively correlated with private worth and produced capital. Countries with a GDP per capita higher than 20,000 US$ have a relatively low number of bird species per log transformed km². Most of the countries have bird species numbers between 20 and 40, with some exceptions such as Singapore (SGP), the United States (USA), Brunei Darussalam (BRN) and Trinidad and Tobago (TTO) with values between 50 and 60.

On the other hand, in the majority of the countries people live from less than 20,000 US$ per year, but these countries have a higher range of bird diversity. The lowest values have Tajikistan (TJK) with 38.2 and Uzbekistan (UZB) with 38.7 animal species per log transformed km². Countries with the highest animal diversity are Indonesia (IDN) with 369.4, and Colombia (COL) with 303.6.

Species diversity and biotic factors do not indicate strong correlations with socioeconomic and demographic factors. Negative correlations exist between infrastructure and bird species, and between biocapacity and population density.

Most of the socioeconomic variables are negatively correlated with species diversity, except for the Gini Index.
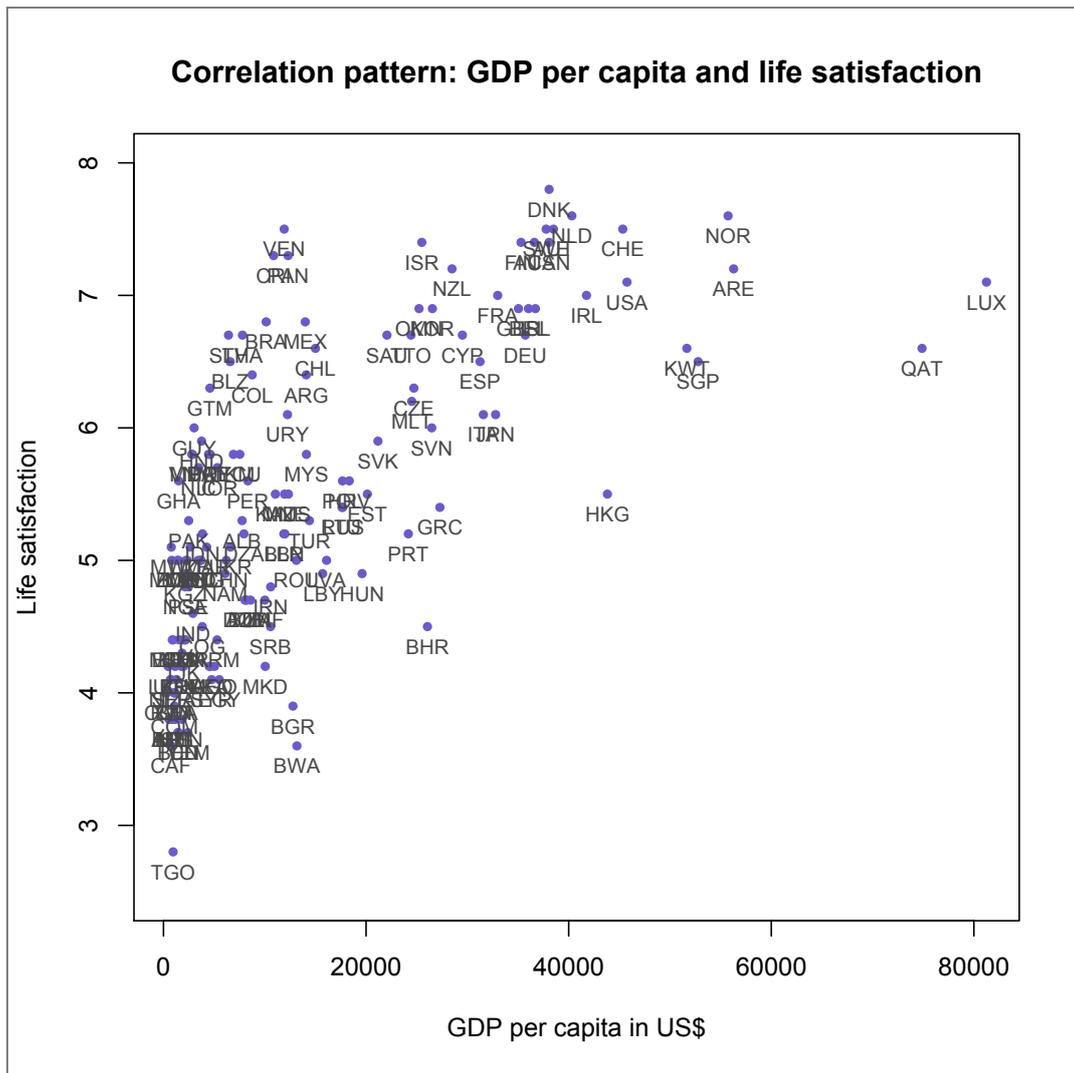
Fig. 1: The scatterplot of the correlation between GDP per capita and life satisfaction shows a significant positive correlation.

Economic factors correlate strongly with socioeconomic & demographic factors, for example GDP per capita with education, economic freedom, globalization, life expectancy, and urbanization. With some exceptions, all variables from the two groups are positively correlated. Exceptions are agricultural share, GDP growth and net foreign assets. These correlate negatively with socioeconomic variables. Countries that have a high GDP per capita experience low GDP growth rates. Net foreign assets are negatively correlated with socioeconomic factors as well.

Life satisfaction correlates strongly with economic factors, especially income. However, figure 1 shows that after a certain level of GDP, increases in life satisfaction do not follow income gains to the same extent

On the other hand, the correlation between life satisfaction and bird species diversity is weak. The majority of the countries has a bird diversity lower than 60 bird species per log transformed km², but covers a broad range of different life satisfaction values (see figure

2) Latin American countries are statistical outliers. Countries such as Venezuela (VEN), Costa Rica (CRI), Panama (PAN), Brazil (BRA), and Colombia (COL) have significantly higher bird diversity and life satisfaction than the average
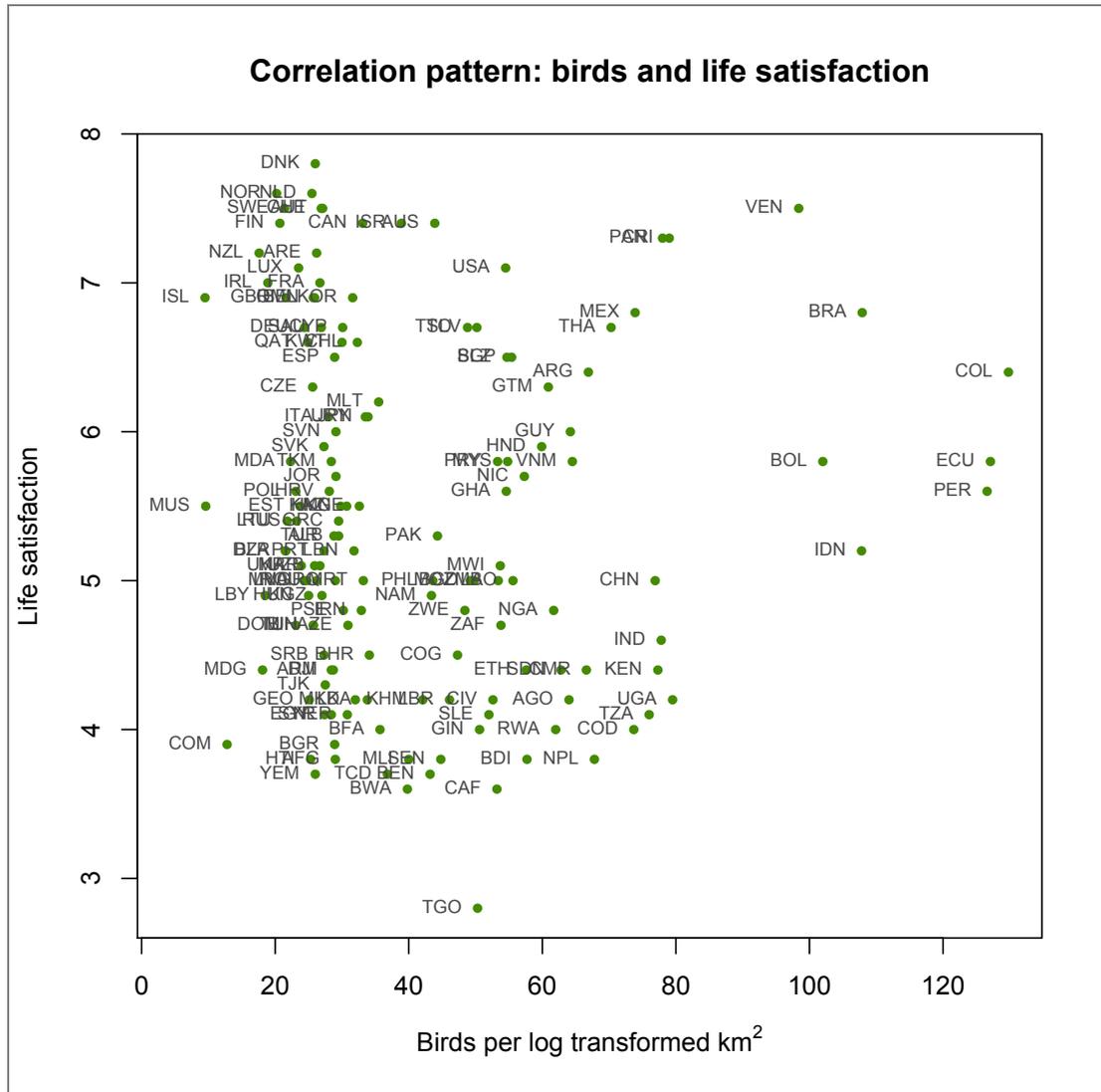

Fig. 2:   The scatterplot of the correlation between birds and life satisfaction shows no significant correlation. Most of the countries have a bird diversity lower than 60 and a broad range of life satisfaction values, while some outliers have high biodiversity, and life satisfaction between average and above-average.

Furthermore, life satisfaction correlates with biocapacity, forest cover, protected area, and subsoil assets.

Among the social factors, very strong correlations between life satisfaction and globalization and between life satisfaction and life expectancy exist. The correlations with democracy, education and economic freedom are also strong. Abiotic factors such as temperature and precipitation seasonality correlate with life satisfaction.

The interactions between **species diversity and abiotic factors** indicate a strong correlation of area size with species diversity. Climatic variables weakly correlate with

variables representing biodiversity, especially with the biotic factors forest cover and net primary productivity. The correlations between climatic variables and species diversity variables are low. However, as biotic factors are related to species diversity, climatic variables could be related to species diversity via this path.

5.1.2   Tree model and cluster analysis

For both GDP and bird species diversity, the range between the lowest and highest values is big. Relatively few countries reach intermediate values for both variables. According to the variable GDP per capita, the dataset seems to be divided into two groups with relatively homogenous characteristics. In this case, it makes sense to define different groups and to analyse them individually. The results will be described in this section.
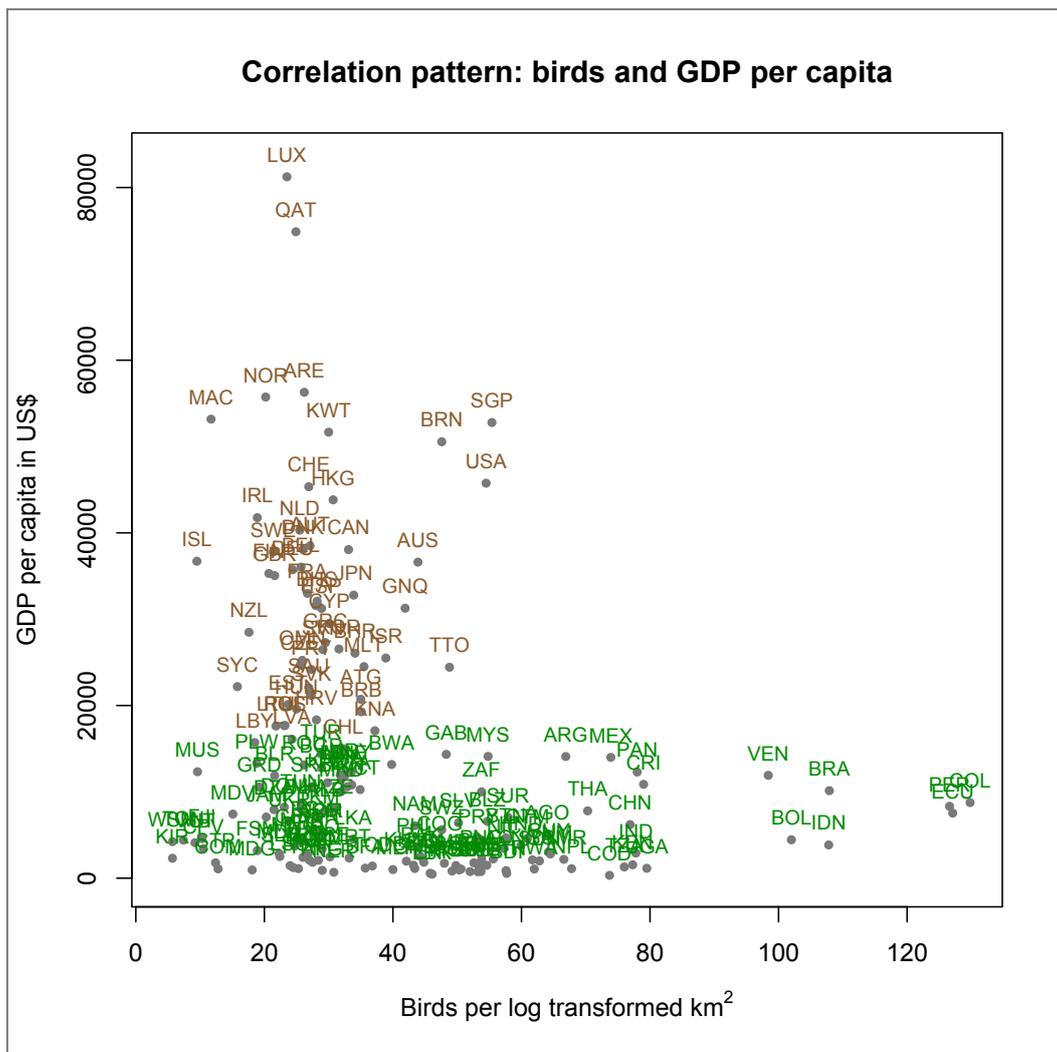

Fig. 3:   The scatterplot shows a negative correlation between birds and GDP per capita. Countries with an income lower than 14371.2 US$ are highlighted in green. Their average number of bird species is higher than in the countries with a GDP higher than 14371.2 US$, highlighted in brown.

Figure 3 with the country codes[7] in different colours illustrates the division into two income groups. Countries with orange ISO code letters have a high GDP value and a relatively small number of birds per area. Countries with green ISO code letters experience a low GDP per capita, but a broad range of bird species diversity. The overall pattern is a negative relationship between birds and GDP per capita. However, this could be different in the income groups. First, the data set was divided with the **tree model**, using the GDP and the number of bird species as main characteristics. The output is a division into a low-income and a high-income (tree model) group, with a threshold value of 14371.2 US$. The boxplot shows how significantly the number of bird species in the two income groups differs. Low-income countries not only have a higher median of bird species numbers, but also more than double the range of high-income countries.
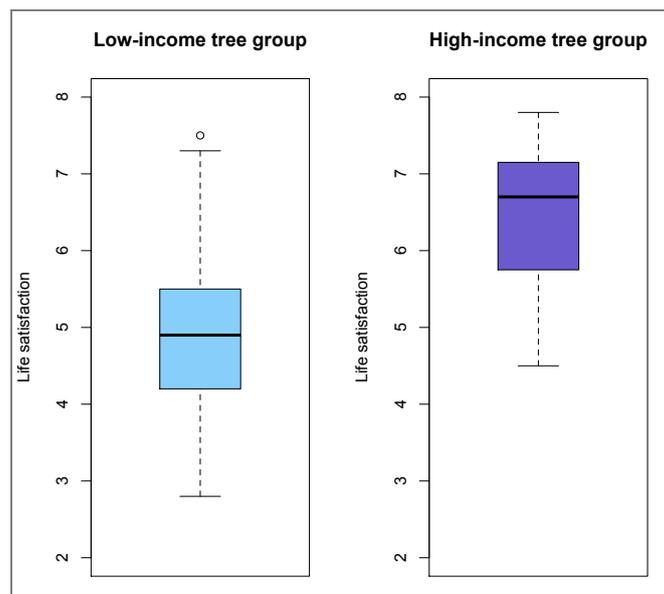

Fig. 4:   The boxplots for life satisfaction in the low-income and high-income group (obtained with the tree model) shows that high-income countries have higher life satisfaction than low-income countries.

Furthermore, life satisfaction is, on average, significantly higher in high-income countries than in low-income countries. Additionally, the correlation pattern between birds and life satisfaction differs in the two income groups. In low-income countries, the correlation between birds and life satisfaction is significantly positive, while it is slightly positive but not significant in high-income countries. Latin American countries have a high bird diversity and above-average life satisfaction as compared to other low-income countries.

Another method to obtain homogenous groups in the dataset is a **cluster analysis**. This yields one large group with 66 countries mostly contains low-income countries from Africa, South America, Eastern Europe and Asia. The other cluster group contains 29 high-

[7] Country codes according to the International Organization for Standardization (ISO)

income countries, such as Austria, Sweden, Finland, Denmark, Ireland, the UK, Germany, the United States, Japan, Croatia, Latvia, Hungary, the United Arab Emirates and Singapore. Similar to the tree model, the cluster analysis resulted in a low- and a high-income group. As a result, income seems to be a very significant characteristic for the data set.

In summary, one low- and high-income group was obtained with the tree model, and another low- and high-income group was obtained with the cluster analysis. A shortcoming of both grouping methods is that the income groups significantly differ in their sample sizes. The low-income (tree model) group contains 128 countries, whereas the high-income (tree model) group contains only 56 countries due to missing values. These limitations will further be discussed in chapter 9.

However, as the sample sizes of the income groups differ between the tree model and the cluster analysis, the results can be compared to see if they are robust to small changes. Figure 5 shows that the results of the tree model groups are similar to the results of the cluster groups. The only small difference is that the ranges of the second and third quintile of the high-income tree group are bigger than those of the high-income cluster group. However, as median and range are consistent, figure 5 shows: Countries with incomes lower than around 15,000 US$ have a higher number of bird species than countries with incomes higher than around 15,000 US$.

The different grouping methods allow the calculation of GLMs for the different income groups. Results can be compared for their validation.
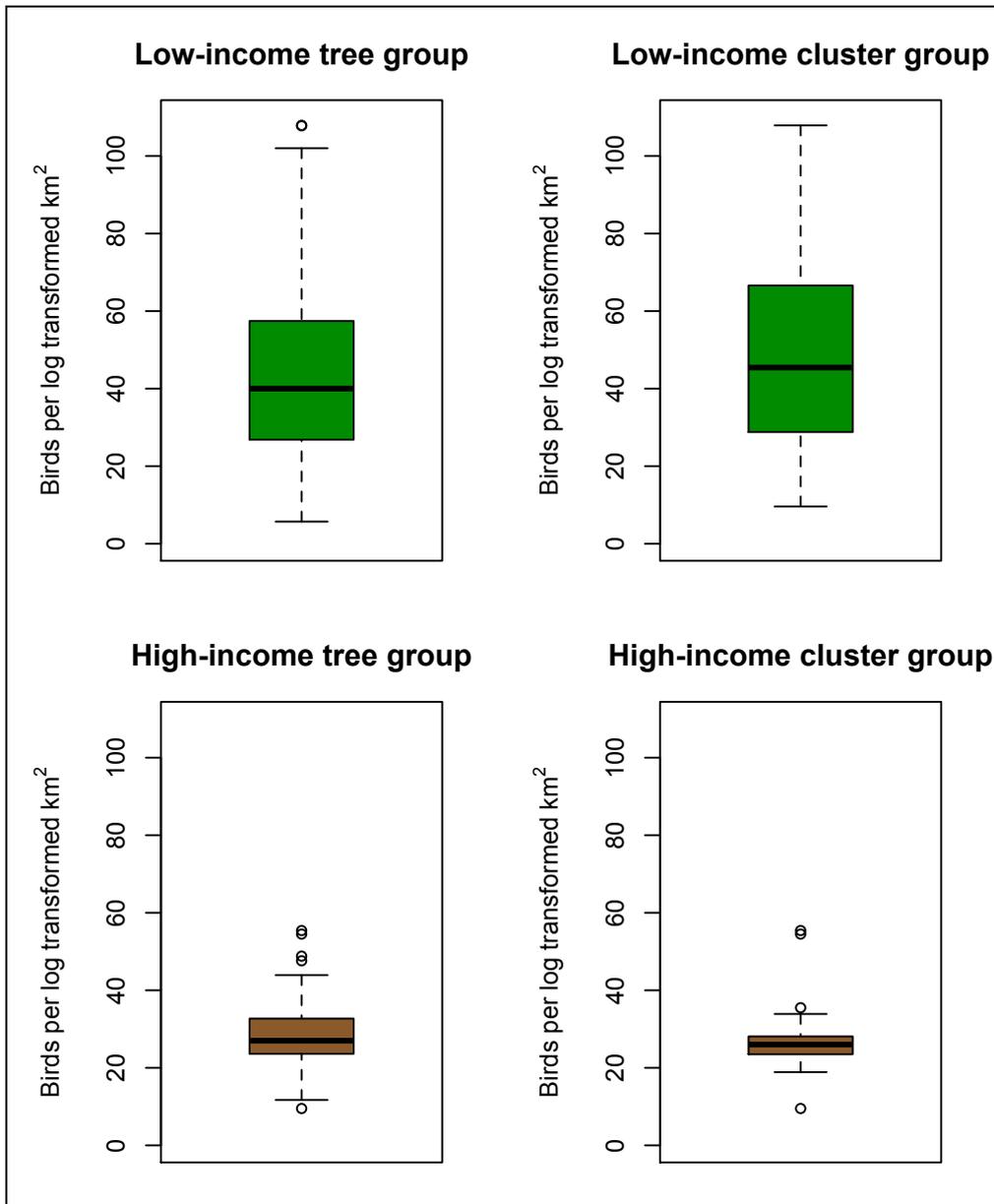
Fig. 5:   The four boxplots show the number of bird species in the different income groups. Both clustering methods result significantly higher bird species diversity in low-income countries than in high-income countries.

5.2   Univariate relations of biodiversity and well-being, and biodiversity and economic wealth

This chapter presents and discusses the regression results for generalized linear models (GLMs). It is divided into the two relationships, biodiversity and well-being, and biodiversity and economic wealth.

5.2.1   Biodiversity and well-being

Linear correlations and GLMs indicate **a positive relationship between biodiversity and well-being in low-income countries.** In the GLMs of both low-income groups, the

variable birds is correlated with life satisfaction at a 0.000 significance level. Other significant variables are life expectancy (positive estimate), democracy (positive estimate), NFA (negative estimate) and Gini (positive estimate), and GDP per capita (only in the low-income cluster group).

Table 2: GLMs for both low-income groups with life satisfaction as response variable and birds, life expectancy, democracy, net foreign assets, Gini Index, and GDP per capita as explanatory variables.. They show a significant positive correlation between birds and life satisfaction and other variables that are significantly correlated with life satisfaction.

Low-income groups			*85 observations*						*66 observations*	
Tree model	Estimate	Std. Error	t value	Pr(>|t|)		**Cluster group**	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-7.58E-01	6.58E-01	-1.152	2.53E-01		(Intercept)	0.7279	0.8811	0.826	0.4119
St_Birds	1.10E-02	2.84E-03	3.868	2.24E-04	***	St_Birds	0.01359	0.00303	4.485	0.0000 ***
LifeExp	5.71E-02	8.44E-03	6.766	2.09E-09	***	GDP	6.1E-05	1.8E-05	3.353	0.0014 **
Democ	8.98E-02	4.58E-02	1.960	5.35E-02	.	LifeExp	0.04935	0.01326	3.723	0.0004 ***
NFA	-1.15E-04	6.65E-05	-1.731	8.74E-02	.					
Gini	1.98E-02	8.39E-03	2.356	2.09E-02	*					
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1										

Table 2 shows a significant correlation between biodiversity and life satisfaction. Birds and biocapacity, as another indicator for biodiversity, are positively correlated with life satisfaction on a 0.01 significance level. Highly significant correlations were found between GDP per capita and life satisfaction, and between life expectancy and life satisfaction.

Table 3: GLM for the whole dataset with life satisfaction as response variable and temperature range, birds, biocapacity, population density, GDP per capita, life expectancy, unemployment and urbanization as explanatory variables. It shows a significant correlation between birds and life satisfaction. Other more significant correlations with life satisfaction are obtained with GDP per capita, life expectancy, and urbanization.

				111 observations	
Whole dataset	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	1.59E+00	7.50E-01	2.123	3.62E-02	*
TempRange	-2.00E-02	7.76E-03	-2.580	1.13E-02	*
St_Birds	7.16E-03	2.93E-03	2.440	1.64E-02	*
Biocap	4.06E-02	1.87E-02	2.168	3.25E-02	*
PopDens	-1.96E-04	9.08E-05	-2.158	3.33E-02	*
GDP	3.14E-05	6.06E-06	5.178	1.13E-06	***
LifeExp	4.39E-02	1.06E-02	4.152	6.86E-05	***
Unempl	-2.15E-02	9.51E-03	-2.260	2.60E-02	*
Urb	1.11E-02	4.17E-03	2.668	8.88E-03	**
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

The VIFs of all the variables employed in the models are lower than four. Consequently, the conjoint use of the variables does not distort the results.

In the high-income groups, birds do not correlate with life satisfaction as significantly as in the low-income groups (see table 4). While the estimate is slightly positive with a significance level at 0.05 in the high-income tree group, it is not significant in the high-income cluster group.

Table 4: GLMs for the high-income groups with life satisfaction as response variable and birds, temperature range, biocapacity, population density, life expectancy, unemployment, and education as explanatory variables. They show weak correlations between birds and life satisfaction. Other variables strongly correlating with life satisfaction are life expectancy, unemployment, biocapacity, and GDP per capita.

High-income groups		38 observations					29 observations		
Tree model	Estimate	Std. Error	t value	Pr(>|t|)	Cluster group	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-6.73E-01	2.18E+00	-0.308	7.60E-01	(Intercept)	3.37E+00	1.14E+00	2.954	6.74E-03 **
St_Birds	2.51E-02	1.33E-02	1.887	6.86E-02 .	GDP	4.16E-05	8.64E-06	4.817	5.99E-05 ***
TempRange	-3.75E-02	1.44E-02	-2.612	1.37E-02 *	St_Birds	-1.58E-02	1.33E-02	-1.19	2.45E-01
Biocap	8.33E-02	2.89E-02	2.882	7.11E-03 **	Edu	2.04E-01	1.02E-01	2.007	5.57E-02 .
PopDens	-2.72E-04	1.05E-04	-2.606	1.40E-02 *					
LifeExp	1.06E-01	2.60E-02	4.103	2.74E-04 ***					
Unempl	-1.46E-01	3.14E-02	-4.649	5.85E-05 ***					
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1									

5.2.2 Biodiversity and economic wealth

The correlation between biodiversity and economic wealth is negative throughout the linear correlations and the GLMs. In the linear correlation and the GLM for the whole dataset, the estimate of the variable birds is negative and significant at a 0.001 to 0.000 level (see table 5). Other variables significantly correlate with GDP per capita, such as agriculture (negative estimate) and life expectancy (positive estimate). Urbanization, and economic freedom correlate positively with GDP per capita at lower significance level (both at 0.01), whereas unemployment is negatively correlated with GDP per capita.

Table 5: GLM for the whole dataset with GDP per capita as response variable and birds, agriculture, life expectancy, urbanization, economic freedom and unemployment as explanatory variables. It shows a negative and significant correlation between birds and GDP per capita.

Whole dataset	Estimate	Std. Error	t value	Pr(>|t|)	
			121 observations		
(Intercept)	6.99E+00	6.71E-01	10.419	< 2e-16	***
St_Birds	-4.47E-03	1.56E-03	-2.863	4.99E-03	**
Agr	-8.81E-02	8.67E-03	-10.163	< 2e-16	***
LifeExp	3.30E-02	8.46E-03	3.899	1.63E-04	***
Urb	5.35E-03	2.13E-03	2.517	1.32E-02	*
EconFree	1.06E-02	4.15E-03	2.559	1.18E-02	*
Unempl	-1.96E-02	7.48E-03	-2.614	1.02E-02	*
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

The negative relationship pattern remains in the different income groups. In the low-income groups, the estimate of birds is negative and significant at a 0.05 to 0.01 level (see table 6). For the high-income groups, the significance level varies between the 0.01 and 0.000 level (see table 7). As a result, the negative correlation between biodiversity and economic wealth seems to persist throughout different income groups.

Table 6: GLMs for both low-income groups with GDP as response variable and birds, education, agriculture, subsoil assets, urbanization, life expectancy, economic freedom, and democracy as explanatory variables. They show a negative and slightly significant correlation between birds and GDP per capita. The interaction of birds with education is positively correlated with GDP per capita at a low significance level (0.05).

GDP: Low-income groups			98 observations		Cluster group			66 observations	
Tree model	Estimate	Std. Error	t value	Pr(>|t|)	Cluster group	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	6.99E+00	5.36E-01	13.042	< 2e-16 ***	(Intercept)	8.22E+00	7.10E-01	11.572	< 2e-16 ***
St_Birds	-1.14E-02	5.50E-03	-2.077	4.07E-02 *	St_Birds	-1.89E-02	9.46E-03	-1.999	5.03E-02 .
Edu	-2.51E-02	2.18E-02	-1.152	2.52E-01	Edu	-7.16E-02	5.20E-02	-1.378	1.73E-01
Agr	-4.47E-02	6.08E-03	-7.351	9.13E-11 ***	Agr	-6.65E-02	8.56E-03	-7.769	1.50E-10 ***
Subs	3.24E-13	1.92E-13	1.686	9.53E-02 .	Subs	2.60E-13	7.36E-14	3.525	8.34E-04 ***
Urb	8.93E-03	2.32E-03	3.856	2.18E-04 ***	LifeExp	2.26E-02	7.29E-03	3.095	0.003 **
LifeExp	1.95E-02	5.62E-03	3.474	7.95E-04 ***	Democ	6.90E-02	3.25E-02	2.12	3.83E-02 *
EconFree	1.09E-02	4.78E-03	2.275	2.53E-02 *	St_Birds*Edu	2.19E-03	1.19E-03	1.84	0.0708 .
St_Birds*Edu	1.32E-03	7.02E-04	1.886	6.26E-02 .					
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1									

When interactions between different variables are included, the interaction between birds and education changes the negative correlation pattern. Individually, these variables correlate negatively with GDP per capita, but, when tested for their interaction, the estimate changes to a positive sign.

In other words, **the interaction between birds and education positively correlates with GDP per capita**. The significance level in the high-income groups (0.01 to 0.000) is higher than in the low-income groups (0.05).

Again, all VIFs are smaller than four, except the variables that are tested for interactions.

Table 7: GLMs for both high-income groups with GDP as response variable and birds, education, life expectancy, unemployment, globalization, and net foreign assets as explanatory variables. They show a negative correlation between birds and GDP per capita at significance levels between 0.01 and 0.000. They also show that the interaction of birds with education is positively correlated with life satisfaction at significance levels between 0.01 and 0.000.

GDP: High-income groups			39 observations		Cluster group			29 observations	
Tree model	Estimate	Std. Error	t value	Pr(>|t|)	Cluster group	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	9.56E+00	1.19E+00	8.039	4.46E-09 ***	(Intercept)	8.56E+00	1.33E+00	6.446	2.18E-06 ***
St_Birds	-6.68E-02	2.68E-02	-2.488	1.84E-02 *	St_Birds	-9.98E-02	2.52E-02	-3.967	7.03E-04 ***
Edu	-1.93E-01	7.85E-02	-2.459	1.97E-02 *	Edu	-2.59E-01	7.56E-02	-3.42	0.0026 **
LifeExp	3.10E-02	1.20E-02	2.579	1.49E-02 *	LifeExp	5.34E-02	1.43E-02	3.743	1.20E-03 **
Unempl	-4.56E-02	1.43E-02	-3.185	3.29E-03 **	NFA	7.51E-06	1.06E-06	7.103	5.25E-07 ***
Glob	1.14E-02	3.52E-03	3.241	2.85E-03 **	Glob	1.12E-02	3.05E-03	3.681	1.39E-03 **
NFA	6.15E-06	1.26E-06	4.867	3.14E-05 ***	Unempl	-3.95E-02	1.34E-02	-2.957	0.0075 **
St_Birds*Edu	6.01E-03	2.41E-03	2.499	1.80E-02 *	St_Birds*Edu	8.71E-03	2.22E-03	3.922	7.83E-04 ***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1									

As mentioned in the methods section of this thesis, the GLMs were also calculated using the first principal component axes from the PCAs. This approach did not result any significant correlations.

6 Discussion

Most of the results can be embedded in the context of previous studies. However, since not all of my results were detected before, I also develop explanations by linking the main results to other correlation patterns in the dataset.

6.1 Biodiversity and well-being

Biodiversity is significantly correlated with well-being in low-income countries. Additionally, GDP per capita is significantly correlated with well-being in the whole dataset. In low-income countries however, the variance of income is relatively little. Consequently, the differences in well-being must be driven by other factors than income, such as biodiversity. One possible explanation for the relationship pattern between biodiversity and well-being could be that more people live in close contact with biodiversity in poor countries. The correlation pattern between GDP per capita and agricultural value supports this notion: The poorer a country in terms of GDP per capita, the higher its agricultural value. The cultivation of plants and animals relates people to nature. Healthy ecosystems, as indicated by a higher number of bird species, provide non-market goods and services that contribute to well-being, and people living in close contact to nature profit more than others (see ME Assessment, 2005; World Resources Institute, 2008, and World Resources Institute et al., 2005). The different cultural, psychological and recreational valuable goods and services can significantly contribute to human well-being (ME Assessment, 2005; UNEP, 2009).

Latin American countries have a remarkably high life satisfaction in comparison to other countries in the low-income group. High biodiversity and high life satisfaction distinguish these countries from other low-income countries. Consequently, biodiversity seems to be closely related to well-being in Latin American countries. However, this relationship can have other reasons as well. The discussed countries are located in tropical regions. The relationship between biodiversity and well-being could thus be an artefact because of the species-energy relationship. This means that countries in the tropics have more species than at northern and southern latitudes. This is accounted for via the inclusion of climatic variables such as precipitation and temperature as confounding factors.

Furthermore, Rehdanz (2007) discovered spatial correlations for life satisfaction. This means that life satisfaction must not change with national boundaries. In other words, neighbouring countries can influence each other's life satisfaction. Many Latin American countries have similar historic and cultural backgrounds, such as the Spanish colonial era, fights for independence and religion, as a large number of Latin Americans are catholic. A

potential explanation for the high life satisfaction might be cultural background. In order to further investigate this, it would be necessary to integrate these aspects into a statistical analysis.

In contrast to this result, there is no significant correlation between life satisfaction and biodiversity in the high-income groups. Results in the high-income groups appear to be sensitive to minor changes in the sample group, wonce the inclusion or exclusion of a small number of countries leads to a change in the estimate sign and the significance level of the variable Birds. The sample size of the high-income tree group is 38, whereas the sample size of the high-income cluster group is 29. Due to this sensitivity to small changes, the results cannot be taken as robust.

Other factors than biodiversity seem to play a more important role for well-being, such as economic wealth or education. Other aspects, such as unemployment and life expectancy, seem to be important as well. Also biocapacity, population density and the temperature range correlate with life satisfaction (see table 3, p. 23). The importance of temperature range is consistent with the findings of Rehdanz and Maddison (2005), who have shown that people living in countries where the difference between the temperature of the coldest and the hottest month is high are less satisfied with their lives. In addition, unemployment negatively correlates with life satisfaction. Having a job seems to affect life satisfaction more than having a high income. In other words, self-fulfilment, social interactions in the workplace and the feeling of having responsibility seem to be crucial for life satisfaction in high-income countries where basic material wants have been met. Similarly, Frey and Stutzer (2002, p. 5) already pointed out the negative relationship between unemployment and happiness. The findings also partly support the idea of Diener and Oishi (2003, p.186), who think of self-development, love, and spirituality as more important human goals than economic wealth. Capturing and integrating these aspects into an analysis can be subject to future research.

6.2   Biodiversity and economic wealth

Biodiversity correlates negatively with economic wealth throughout all different income groups. This persisting pattern indicates that species diversity is negatively correlated with increasing incomes, and is consistent with Asafu-Adjaye's (2003), Dietz et al.'s (2012), and McPherson and Nieswiadomy's (2005) findings. One explanation for this relationship is that activities contributing to economic wealth, such as the conversion of natural habitats into agricultural and urban areas (Rockström et al., 2009a, p. 474), lead to losses in biodiversity. Forests are cleared to harvest timber to increase incomes. Timber is obviously more valuable than the ecosystem services that people obtain from the forest,

such as fresh air or possibilities for recreation. One reason for this is that such services are not captured by the market and therefore have no economic value (Dasgupta, 2001; Freeman, 1993, p. 107). The valuable resource is timber, resulting in the depletion of the natural resource in order to increase economic wealth.

These increases in economic wealth in turn are related to human well-being. At the same time, accompanying losses in biodiversity result in decreases in well-being. However, increases in well-being obtained from economic wealth gains can potentially outweigh the decreases in well-being from biodiversity loss. This theory can be related to the Environmentalist's paradox: While human well-being increases, ecosystems degrade and biodiversity declines (Raudsepp-Hearne et al., 2010).

Furthermore, declines in biodiversity are, according to this study's result, not overcome in high-income countries. The EKC theory hypothesizes the turn over of the negative relationship between biodiversity and economic wealth after a certain point of economic wealth (Asafu-Adjaye, 2003; Holland et al., 2009; McPherson and Nieswiadomy, 2005). This study's results do not support this theory.

Recent research has shown that activities related to economic wealth have long-term consequences for biodiversity loss. Dullinger et al. (2013) and Helm et al. (2005) identified that the response of losses in species diversity to habitat loss and fragmentation is subject to time-delays. This means that "species populations [especially long-lived or less-mobile taxa] do not necessarily respond immediately to environmental degradation but might do so with a delay" (Dullinger et al., 2013, p. 1). Considering this, it is likely that the negative effect of anthropogenic pressures on species diversity is underestimated, so that extinction rates might become significantly higher than we experience them now.

This negative relationship between biodiversity and economic wealth is significant. Due to other studies with the same results, it is very likely that the result is robust and not an artefact. The negative impact of economic wealth on biodiversity could even be higher than estimated if observed over a longer time period. Conservation efforts must take this into account in order to establish a long-lasting monitoring and protection programme for global biodiversity.

Another result is that the interaction of bird species diversity and education correlates positively with GDP per capita, especially in high-income countries. Countries with a relatively high biodiversity and with a population that, on average, has longer school education experience more economic wealth.

One reason for this correlation could be that people who go, on average, to school longer are better educated about their natural environment and its value for society. Countries

where these people live are likely to have scientific institutes that help exploring and understanding biological systems and their benefits for society. As a result, they might also have a stronger interest in nature conservation and be better endowed with financial resources for investments in conservation efforts.

Since other studies have not detected such a correlation, it is important to further investigate the role of education, in combination with biodiversity, on economic wealth.

In the next chapter, limitations and further areas for future research will be elucidated.

7   Limitations and future research

As mentioned before, it is important to be aware of the fact that all the results are neither definite confirmations nor refusals of the relationships between biodiversity and economic wealth, and between biodiversity and well-being. GLMs are always limited to a certain amount of confounding factors that are observable and for which data is obtainable. Consequently, the inclusion of further factors could change the results. However, due to the inclusion of many factors and a thorough statistical analysis the findings of this study suggest that the relationship between the different variables is more than coincidental. The following chapter proposes some directions for further research that could contribute to more robust results.

As the analysis was made on a global scale, we can only make a small contribution to a better understanding of the relationship between biodiversity, economic wealth and individual well-being. It is necessary to more closely examine the detected relationships and the different data sets employed. For this reason, this section also outlines possible improvements to the data and methodology.

First of all, one shortcoming already mentioned is the lack of suitable data on a global level for many of the variables. For biodiversity it was possible to retrieve data, but as "we have only a limited idea of how many different species or forms of life share the planet Earth with us" (Stork, 1993, p. 215), it is not complete. Consequently, it is impossible to reflect the real number of existing species. However, the data employed should represent a good indicator for differences in species diversity between countries. When it comes to economic and socioeconomic data, the shortcomings are more obvious. As for economic stocks, data is not available for a broad range of countries and the data collection methods differ, hence, the data is not always comparable.

For numerous variables, the sample size could be increased. For example, data on the Gini Index only covers 157 countries, and many developing nations are missing. Improvement of data collection for these countries is especially important because results would be biased due to sample selection. Also, a more comprehensive assessment of the relationship between biodiversity and life satisfaction would be possible if data were available for more countries. Since life satisfaction is only available for 151 countries, a bigger sample could significantly improve the analysis, especially in the high-income groups where the sample is too small for reliable statements.

Furthermore, it is probable that more factors, for which no data is available, influence well-being and economic wealth. Omitted variables – either variables that were not

included or confounding factors that are not observable – can interfere and lead to biased estimates. In this case, the detected relationship between biodiversity, economic wealth and individual well-being could be artefacts. To address this, this study covers as many aspects as possible to explain the dependent variables life satisfaction, per capita GDP, and biodiversity. However, there can always be other confounding factors. For example, data reflecting social interactions, the stability of social networks or the cultural background could to be explanatory for well-being and economic wealth. However, as these factors are not easily observable, little data is available. Data on the quality of administration, for example, is available from the World Bank, but the sample size of 78 countries is too small and the variation in the dataset (min=2, max= 4) is too little to allow for a quantitative analysis. The collection of suitable data and their integration into analysis could possibly reveal new relationships in the human-nature system.

Another source of error is the simultaneity of causality. This study does not reveal the direction of causality (see Dolan et al., 2008). As mentioned in chapter 3.a.i., variables for the explanation of life satisfaction can themselves be influenced by life satisfaction, for example life expectancy. It is likely that higher life expectancy not only contributes to an individual's life satisfaction, but that satisfied individuals also have higher life expectancy. The assessment of the direction of causality is only possible with panel data. For some of the variables, it is difficult to obtain data for a row of several years. Future research could concentrate on the collection of panel data and conduct a time-series analysis of the relationship between biodiversity, economic wealth, and individual well-being.

Another method that can be applied for a comprehensive understanding of the relationship between biodiversity, economic wealth and well-being is structural equation modeling (SEM). With SEM, it is possible to create a latent variable that is not directly measurable or observable via the existent variables. Then the causal relationships between these different latent variables can be tested. For this analysis, this could mean that every group forms one latent variable. For example, socioeconomic aspects would be aggregated as one variable. The same happens to socio-demographic, abiotic, biotic and economic factors as well as species numbers. In the end, SEM is expected to reveal each of the groups' influence on the dependent variable. Instead of the relationships between individual variables, it would be possible to detect the *types* of most determining factors for life satisfaction and economic wealth. This could, for example, answer the question if biodiversity, represented by an aggregate of different measurements, correlates with well-being to the same extent as socioeconomic and economic aggregates.

8   Conclusion

The main results of this study about the relationship between biodiversity, economic wealth and individual well-being indicate that 1) biodiversity, measured via bird species diversity, significantly contributes to well-being, measured via life satisfaction, in low-income countries and that 2) economic wealth is negatively related to biodiversity.

In other words, low-income countries seem to depend on or be related to natural assets for their livelihood and wellbeing. At the same time, both low-income and high-income countries seem to destroy this capital with activities fostering economic wealth. This study suggests that increases in per capita GDP lead to losses in species diversity and thereby destroy our Earth's natural capital. As increasing economic wealth is one of the central political goals of many economies, only a rethinking of this paradigm could possibly halt biodiversity loss.

As the relationship between economic wealth and well-being is positive, but the relationship between biodiversity and economic wealth is negative, biodiversity conservation seems be subject to trade-offs with economic wealth. However, both economic wealth and biodiversity seem to be closely related to well-being. As a consequence, politics should balance these relationships in order to increase well-being.

This study's result No. 3) indicates one possible way to do this. The interaction of biodiversity and education correlates positively with economic wealth. This means that a high biodiversity, combined with a good educational system, could be related to income increases. As a consequence, enhancing a nation's educational system could turn the negative relationship between biodiversity and economic wealth.

The implications of these findings for politics can be that first, the value of biodiversity for well-being, especially in low-income countries, must be recognized and transformed into policies. This has already been addressed with the Convention on Biological Diversity, which was agreed on in 1992 by world leaders, with the goal to reduce the rate of biodiversity loss and to increase the benefits that low-income countries obtain from biodiversity (UN, 1992; UNEP, 2011). However, as such policies have not been very successful yet in their goal of preventing further biodiversity loss (Butchart et al., 2010), their implementation must be improved.

Second, countries must become more aware of the adverse effect of economic wealth on biodiversity. As the negative relationship disclosed in this study could even be more significant when time-lags are considered, these nations must sooner or later consider

paradigm shifts in order to not completely destroy their biodiversity. They should move away from the ultimate goal of economic wealth towards the point where the maximization of individual well-being is more important. One step for this would be the adoption of alternative welfare indicators that take into account social and environmental aspects that impact well-being and not only income. Examples are the Index of Sustainable Economic Welfare, the Genuine Progress Indicator, or the German National Welfare Indicator[8].

Third, as the trade-off between biodiversity conservation and economic wealth could possibly be overcome with a good educational system, nations could promote this fact and integrate it into national strategies on economic wealth as well as biodiversity conservation. Rather than investing in economic activities that directly contribute to biodiversity loss, such as deforestation, investments could be steered towards the educational sector. Education can enhance knowledge on biodiversity and create employment opportunities and thereby contribute to biodiversity conservation and economic wealth at the same time. With reservation to its limitations, this study seems to suggest that a high quality of education combined with an intact nature could be related to economic wealth.

Many nations, especially with high incomes, have the necessary means for these investments at their disposal as well as the power to put these findings into practice and to balance the relationship between biodiversity, economic wealth, and individual well-being.

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[8] For more information on alternative welfare indicators, see European Commission (2010)

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Appendix 1)   Dataset overview

Abbr.	Description	Format	Source	Year & Size	Processing
Species Diversity					
Anim	Total number of known *native* animals in a country, categorized by their threat status[1]	PDF	International Union for Conservation of Nature and Natural Resources (IUCN) 2012[2]	2012: 212 countries	Standardized per log transformed area [km^2]
Birds	Number of known bird species in a country	Web	BirdLife International 2013[3]	2013: 210 countries	Standardized per log transformed area [km^2]
Plants	Total number of *native* plants in each country, categorized by their threat status[4]	PDF	IUCN 2012[5]	2012: 209 countries	Standardized per log transformed area [km^2]
Economic Wealth					
GDP	Gross domestic product as purchasing power parity rates in international $ per capita. Sum of all productions made in a country in one year, plus taxes and minus subsidies, without depreciation or degradation of natural resources (World Bank 2013)[6]	Excel	World Bank Data	Averaged over 2005-2011: 183 countries	
Well-being					
LifeSat	Overall life satisfaction range: 0 (least satisfied) – 10 (most satisfied)	Excel	Gallup World Poll 2012 from HDR (2013)[7]	2007-2011: 151 countries	

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[1] "Includes only certain distributions, reintroduced species and regionally extinct species (… excludes all uncertain distributions, introduced species and vagrant records)" (IUCN 2012).

[2] http://www.iucnredlist.org/about/summary-statistics#Tables_5_6 [14/03/2013]

[3] http://www.birdlife.org/datazone/country [25/03/13]

[4] "Includes only certain distributions, reintroduced species and regionally extinct species (… excludes all uncertain distributions, introduced species and vagrant records)" (IUCN 2012).

[5] http://www.iucnredlist.org/about/summary-statistics#Tables_5_6 [14/03/2013]

[6] http://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD [11/03/13]

[7] http://hdr.undp.org/en/statistics/data/ [22/04/2013]

Abiotic Factors				
Land	Total land area of a country in km^2 excluding area under water bodies such as major rivers or lakes and exclusive economic zones (World Bank 2013)[1]	Excel	World Bank Data	Year 2010: 213 countries
Prec	Mean annual precipitation in mm	ESRI GIS	Worldclim bioclim	212 countries
Prec Seas	Precipitation seasonality as the coefficient of variation	ESRI GIS	Worldclim bioclim	212 countries
Area	Total land area of a country in km^2, including water bodies	Excel	World Bank Data	Year 2010: 213 countries
Temp	Mean annual temperature	ESRI GIS	Worldclim bioclim[2]	212 countries
Temp Range	Annual temperature range	ESRI GIS	Worldclim bioclim	212 countries
Biotic Factors				
Biocap	Biocapacity measured in global hectare per person, comprised of cropland, grazing land, forest land, fishing ground and built up land (WWF 2012)	PDF Excel	Global Footprint Network (2007)[3]	2007-2008: (latest year available used) 152 countries
ForCov	Forest cover of a country in % of its total area	Excel	FAO 2010[4]	2010: 197 countries
NPP	Mean net primary productivity, measured in units of elemental carbon	GIS Grid	SEDAC 2013[5]	1995: 208 countries
Prot Area	Protected area in % of total area of a country	Excel	World Bank Data	Year 2010: 203 countries

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[1] http://data.worldbank.org/indicator/AG.LND.TOTL.K2 [11/03/13]

[2] http://www.worldclim.org/current [25/03/13]

[3] http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_data_and_results/ [29/04/2013]

[4] http://www.fao.org/forestry/fra/62219/en/ [11/03/2013]

[5] http://sedac.ciesin.columbia.edu/data/set/hanpp-net-primary-productivity/data-download [26/03/13]

Economic Factors - Flows					
AdjSav	Adjusted net savings are net national savings plus education expenditure minus energy, mineral and net forest depletion and carbon dioxide in current US\$ (World Bank 2013)[1]	Excel	World Bank Data	Averaged over 2004-2010: 144 countries	Normalised with UN data population data 2010
Agr	Agricultural share (value added) of GDP (in %)[2]	Excel	World Bank Data	Averaged over 2007-2011: 173 countries	
GDP growth	Annual percentage growth rate of GDP at market prices based on constant local currency (World Bank 2013)	Excel	World Bank Data	Averaged over 2005-2011: 196 countries	
Economic Factors - Stocks					
NFA	Net foreign assets per capita, in current local currency	Excel	World Bank 2011[3]	2005:152 countries	
Priv Worth	Private worth per adult in US\$ (in PPP)[4]	PDF Excel	UNU-WIDER [5]	2000: 208 countries	
Prod Cap	Produced capital, measured in 2005 US\$; per capita used	Excel	World Bank 2011[6]	2005: 152 countries	
Socioeconomic and demographic Factors					
Demo	Democracy Index: composed of electoral process and pluralism, functioning of government, political participation, political culture and civil liberties (The Economist 2013)[7]	PDF	The Economist 2013	2012: 167 countries	

[1] http://data.worldbank.org/indicator/NY.ADJ.SVNX.CD [11/03/13]

[2] http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS [22/06/13]

[3] http://data.worldbank.org/data-catalog/wealth-of-nations [22/04/2013]

[4] http://www.wider.unu.edu/publications/working-papers/discussion-papers/2008/en_GB/dp2008-03/ [16/04/13]

[5] http://www.wider.unu.edu/events/past-events/2006-events/en_GB/05-12-2006/ [16/04/13]

[6] http://data.worldbank.org/data-catalog/wealth-of-nations [22/04/2013]

[7] http://www.eiu.com/public/thankyou_download.aspx?activity=download&campaignid=DemocracyIndex 12 [25/03/13]

Econ Free	Index of Economic Freedom, composed of property rights, freedom from corruption, fiscal freedom, government spending, business freedom, labour freedom, monetary freedom, trade freedom, investment and financial freedom with the range: 0 (minimum)-100 (maximum)	Excel	Heritage Foundation 2013[1]	Year 2013: 177 countries	
Edu	Education level measured as mean years of schooling	Excel	Human Development Report (HDR) 2013	2010: 185 countries	
Gini	"Gini Index measures the extent to which the distribution of income or consumption expenditure among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality." (WorldBank2013)	Excel	World Bank 2013[2]	Averaged over 1985-2011: 157 countries	
Glob	Index of Globalization, including economic flows, economic restrictions, information flows, personal contact and cultural proximity[3]	Excel	ETH Zürich[4]	Averaged over 1970-2010: 187 countries	
Infra	Infrastructure as road network in km2[5]	Excel	World Bank Data	2000-2009: 185 countries (latest year available used)	Normalised per 10km2 land area

[1] http://www.heritage.org/index/ [11/03/13]

[2] http://data.worldbank.org/indicator/SI.POV.GINI[26/03/13]

[3] For detailed information about the variables and weights, see http://globalization.kof.ethz.ch/

[4] http://globalization.kof.ethz.ch/query/ [08/05/13]

[5] http://data.worldbank.org/indicator/IS.ROD.TOTL.KM [11/03/13]

Life Exp	Life expectancy at birth	Excel	HDR 2013	2012: 191 countries	
Pop	Population (male & female) of all countries	Excel	UNdata[1]	Year 2011: 245 countries	2010 also used
Pop65	Population above 65 years (in % of total population)	Excel	WorldBank[2]		
Pop Dens	Population density = UN population data per km² land area	Excel	UNdata/ WorldBank		
Unemp	Unemployment, % of total labour forces	Excel	World Bank[3]	2005-2011:150 countries	
Urb	Urban population (% of total), living in urban areas as defined by national statistical offices	Excel	WorldBank[4]	2011:210 countries	
Subs	Subsoil assets in 2005 US$	Excel	World Bank[5]	2005: 152 countries	

[1] http://data.un.org/Data.aspx?q=total+population&d=WDI&f=Indicator_Code%3aSP.POP.TOTL [11/03/13]

[2] http://data.worldbank.org/indicator/SP.POP.65UP.TO.ZS [11/06/13]

[3] http://data.worldbank.org/indicator/SL.UEM.TOTL.ZS [10/07/2013]

[4] http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS [22/06/13]

[5] http://data.worldbank.org/data-catalog/wealth-of-nations [22/04/2013]

Appendix 2)   Dataset descriptive statistics

Variable	Description	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
Anim	Total number of animals	30	577	855	1193	1442	5342	2
St_Anim	Number of animals per log transformed km2	4.7	58.6	86.3	105.3	128.6	369.4	3
Birds	Total number of birds	17	243	336	444	591	1811	3
St_Birds	Number of birds per log transformed km2	4.4	24.8	30.8	38.1	49.6	129.8	4
Plants	Total number of plants	4	42	97	185	209	2638	5
St_Plants	Number of plants per log transformed km2	0.5	4.5	8.7	15.2	17.8	211.8	5
GDP	Gross domestic product	324.1	2370	7760.9	13724.2	19867.2	81240.9	31
LifeSat	Life satisfaction	2.8	4.4	5.2	5.4	6.5	7.8	64
ANS	Adjusted net savings	-2185.8	28	214.3	1238.2	1033.1	13208.1	70
Agr	Agricultural value as share of the GDP in %	0	3.1	8.8	13	19.6	60.2	41
GDPgro	GDP growth	-1.3	2.2	4.1	4.3	6	16.0	18
Gini	Gini Index, income distribution	23.9	33.3	39.8	40.6	46.1	69.1	57
Priv Worth	Private worth	960	6561	13924	33814	5.4E+04	2.0E+05	6
NFA	Net foreign assets	-45995	-2014	-544.5	1690.8	-1.3E+02	1.2E+05	62
ProdCap	Produced capital	166	1828	8030	27378	3.2E+04	2.1E+05	62
Biocap	Biocapacity	0	0.7	1.5	2.8	3	28.7	62
ForCov	% of area covered with forest	0	12	33	33	49	95	17
NPP	Net primary productivity	7.8E+09	1.0E+11	3.0E+11	3.4E+11	5.6E+11	1.1E+12	25
ProtArea	Percentage of land with protection status	0	4.0	10.1	12.5	18	60.2	12
Subs	Subsoil assets in US$	0	0	2.2E+09	1.1E+11	5.2E+10	3.5E+12	62
Democ	Democracy Index	1.1	3.6	5.9	5.5	7.2	9.9	48
Edu	Education as mean years of schooling	1.2	5.3	8	7.6	10.1	13.3	29
EconFree	Index of Economic Freedom	1.5	52.5	59.6	59.6	68.1	89.3	39
Glob	Globalization Index	18	34	43	45.4	54.5	84	27
LifeExp	Life expectancy in years	48	65	73	70	76	84	23
Infra	Infrastructure: road network in km per 10km2 area	0.1	1.1	2.8	9.9	9.1	385	29
Pop65	Percentage of population over 65 years	0.4	3.5	5.6	7.7	12	23.4	25
PopDens	Population density in persons per km2	0	34	80	398	196	19416	5
Unempl	Percentage of population unemployed	0.5	4.3	6.9	8.8	10.6	45.1	64
Urb	Percentage of population living in urbanized areas	10.9	38.1	57.7	57.7	76.8	100	4
Area	Country's area inlcuding inland water bodies in km2	2	11300	99900	6.3E+05	4.5E+05	1.7E+07	1
Prec	Mean annual precipitation in mm	0	568	1043	1206	1754	4640	5
PrecSeas	Precipiation seasonality	1.2	3.5	5.7	6	8.4	15.6	6
Temp	Mean annual temperature	-17.1	10.7	22.5	18.6	25.6	28.3	3
TempRange	Temperature range	6.2	14.7	22.3	22.3	29.3	51.1	6