The Ecological Footprint and Biodiversity

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ABSTRACT Environmental sustainability is a multidimensional concept which many analysts approached by using DPSIR (driving force-pressure-state-impact-response) framework. Composite indicators and indices (such as ecological footprint) usually combine different sub-indicators, which reflect different perspectives on the environment, into a unidimensional number. However, in many integrated indicators, measures of state and impact are suppressed compared with driving forces, pressures and responses. Ecological Footprint (EF) is one of the leading composite indicators of environmental sustainability. EF measures human society metabolic demand (i.e. demand for the food, fodder or fibre as well as for the absorption of wastes) on bioproductive areas. Human activities have greatly reduced the amount of area available for biodiversity. The aim of this review is to elaborate possible links between the Ecological Footprint as a measure of environmental sustainability and between biodiversity as a measure of ecosystem integrity. In my contribution, I try to show possible linkages mainly through species-area, species-energy and species-disturbance hypotheses. Convention on Biological Diversity endorsed Ecological Footprint as one of the leading indicators of sustainable use. I review relevant concepts of sustainable use, illustrate possible patterns of EF and biodiversity using the territory of the Czech Republic, and suggest further directions of research and methodology development for indicators of sustainable use of biodiversity.

Conference Theme: Methodology

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Introduction

Ecological Footprint (EF) as a leading indicator of environmental sustainability measures the rate of natural resources consumption and CO_2 emissions assimilation capacity in normalized hypothetical spatial units. The EF concept is based on the notion of space, i.e. that all activities exerted by human society on the environment are related to land which constitute the main resource base for production of goods and absorption of wastes. Ecological Footprint as such doesn’t aim to measure directly impacts of human society on the environment. The EF accounts measure human impacts only indirectly, by incorporating factors that compromise the biosphere's capacity to regenerate. Nonrenewable resources are represented in the accounts by fossil fuels and don't include impacts due to mining, processing, and the consumption of those resources (Wackernagel et al., 2002). Services from biodiversity, local impacts of freshwater use, or the loss of biocapacity due to the release of solid, liquid, and gaseous waste other than CO_2 are also left out. Although the ecological overshoot of human economy signals significant impacts on the biodiversity, the mechanism of this link remains unexplained.

Biodiversity is recognized as the main component of ecological integrity of Earth's systems. Biological diversity, or biodiversity for short, means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity 2006). Conservation and sustainable use of biodiversity are becoming an important part of the global environmental agenda, as the World Summit on Sustainable Development in 2002 reaffirmed the target by 2010 to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth. Why the biodiversity is declining and why the policy target of halting the biodiversity loss became one of the leading targets on global agenda?

The main methodological aspects related to the impacts of the Ecological Footprint on biodiversity are pertaining the structure of the indicator and the mechanism of relationship between the EF and biodiversity. Many composite indices and environmental indicators sets, for example the Environmental Sustainability Index (developed at Yale Center for Environmental Law and Policy) or the Wellbeing Index (Prescott-Allen 2001), include some aspect of biodiversity. However, the nature of the construction of these indices is different from the Ecological Footprint method although they struggle to benchmark countries with regard to their overall environmental performance. As van den Bergh and Verbruggen (1999) observe, the EF does not distinguish between sustainable and unsustainable use of land. They suggest that in order to measure the degree of unsustainability specific indicators are needed that focus on processes that contribute to unsustainability, which would included also unsustainable use of biodiversity, rather than just an overall land area measure. This critics lead to proposals for the modifications of the EF method with the aim to take into account the sustainability of land use practices.

Mechanisms of human impact on biodiversity

The mechanism of the relationships between the EF and biodiversity is far from to be deeply explained and described. There are several biodiversity indicators in use or under development which measure the state of nature (Biggs et al., 2007). The EF calculations at the global, national or regional level usually reserve 12 % of biologically productive area for conservation. This number approximately corresponds to the proportion of protected areas in many countries as well as at the global level: 11.5 % for terrestrial surface of the Earth (Chape et al., 2003). However, there is no quantitative technique to assign “the right” proportion of the land area that should be devoted to biodiversity conservation.

The Living Planet Report (WWF 2006) reports the global state of nature by using as leading indicators the Living Planet Index (LPI), which reflects the health of the Earth’s ecosystems and the Ecological Footprint (EF), which shows the extent of human demand on these ecosystems. The Living Planet Report links the consumption of a civilization to the deterioration of the global biodiversity. The pressure of human society on the environment is generally recognised through the popular equation I = PAT, which expresses environmental impact as a function of population, affluence of consumption and technological efficiency. The greatest impact on the environment thus will exert a society with high population, high rate of consumption of natural resources and low technological efficiency. Myers and Kent (2003) see the main growing impact in an emergence of a diet based strongly on meat and a rising possessions of cars in populous, rapidly developing or transition countries mainly in South-East Asia, South America and Eastern Europe. These countries are very often “megadiverse” countries, which harbour a significant proportion of the world’s biodiversity and contain several “biodiversity hotspots”. Thus the rapid development can probably lead to the further loss of biological diversity.

To map the human footprint, Sanderson et al. (2002) used in their approach similar to the Ecological Footprint four types of data as proxies for human influence: population density, land transformation, accessibility, and electrical power infrastructure. The number of people in a given area is frequently considered as a primary cause of declines in species and ecosystems, with higher human densities leading to higher levels of influence on nature. Sanderson et al. (2002) assigned different scores to land use classes which reflected the level of human impact on ecosystems. The resulting Human Impact Index (HII) sums the human influence on the Earth’s surface. The maximum values are logically found in areas with high settlement density, especially in big cities, while minimum scores were attained in large tracts of primeval forests, deserts and tundra. They also found that majority of the land (60 %) lies along the continuum between these two extremes, in areas of moderate but variable human influence. However, the human footprint approach doesn’t measure the impact per se.

The size and growth of the human population are often cited as key driving forces behind the Earth’s biodiversity loss, yet the extent of their contribution to the endangerment and extinction of other species has remained unclear. The most biodiverse regions of each continent are also considered to be the most threatened by high human population densities and consumption (Liu et al., 2003). Many studies suggest that human population density may be a useful surrogate measure of the impact on biodiversity of a range of activities associated with human settlements. Human density correlates with removal of natural habitat, damage to the environment, and extinction of species (Harcourt et al., 2001). Luck et al. (2004) tried to characterize the level of spatial overlap between densely populated and biodiverse areas and to evaluate options for alleviating potential conflict. They found that human population density strongly positively correlate with species richness and thus the most biodiverse regions are also the most threatened by human impacts.

At global scales, habitat destruction and the introduction of exotic species are the main factors contributing to declines in species diversity. At regional and local scales, evidence for biodiversity declines is mixed, and recent work suggests that diversity might commonly be increasing (Sax, Gaines, 2003). This effect can be ascribed to the biotic homogenization at the regional scale, where introduced species are enriching local fauna and flora and occasionally also create new emerging ecosystems. Olden et al. (2006) report biotic homogenization showing a statistically significant relationship with human population geography for all major taxonomic groups. However, results from this and similar studies suggest that despite the significance of the impact of human population on biotic homogenisation, approximately two thirds of variance remain unexplained and further research is needed to account for this residual variation. Which factors could be responsible for this variation? McKee et al. (2003) suggest that it could be the level of exploitation of natural resources and/or ecological differences between nations. However, they found a strong correlation between human the human population density and species richness with the numbers of threatened species of mammals and birds.

Land cover and land use changes are considered to be a primary factor responsible for the loss of biodiversity. As noted by the Millennium Ecosystem Assessment (MA 2005), over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for natural resources and related ecosystem services. This has resulted in a substantial depletion of services provided to humans by ecosystems and largely irreversible loss of biodiversity. The emerging consumers in developing and transition countries will require additional land for production of food, fiber and fuel. Moreover, with fossil fuel shortages and insecurity of supply, many countries depart on the strategy of biomass substitution. Whereas much current biomass energy is derived as a by-product of other crops, energy production from biomass on a much larger scale will require energy crops (Kheshgi et al., 2000). As many current agricultural yields surpass yields attainable under the natural conditions, the production of energy crops can have substantial implications for the bioproductivity.

What is the mechanism responsible for the human consumption being the main pressure on biodiversity? The biodiversity science struggles to find a “unified theory of biodiversity” which would explain current distribution and changes in biodiversity. I will focus on the effects potentially significant for linking the EF and biodiversity: area, energy and disturbance.

Biodiversity and the area

One of the best established patterns in ecology is that of species-area relationship (SAR) (MacArthur, Wilson 1967). Species-area theory has important implications for the assessment of biodiversity loss due to human expansion. It states that the number of species is increasing with the area sampled and the number of species extinctions is proportional to the habitat reduction. Land consumption by humans thus affects the number of species present in a given area. However, there is established no law how many species should be present in a unit area of a particular land cover or land use parcel. Land transformations can change the composition of an assemblage of species but the overall number of species can be the same. The only real land consumption activity is the permanent sealing of land by anthropogenic expansion or temporal destruction of the Earth's surface related to mining or quarrying. What the Ecological Footprint measures is human demand on biologically productive areas. Theoretically, the positive values of biocapacity should indicate that there is some biodiversity reserve, while the ecological overshoot should indicate that the country's resources are fully utilized and there is a little space for biodiversity left.

To examine the relationship between the Biocapacity and biodiversity, I extracted data from the IUCN Red List dataset on endangered species. Endangered species can be seen as a proxy of overall biodiversity, as more species assessed will list more endangered species. Megadiverse countries, which host 60 – 70 % of the world's biodiversity, have higher proportion of endangered species, although there is no reason to expect higher rates of human threats to biodiversity in these countries in comparison to other countries. There can be found a positive relationship between the Biocapacity and the number of endangered species (Fig. 1). This pattern suggest that available biologically productive areas support biodiversity, although some proportion of that can be deteriorated or endangered.

Biodiversity and the energy

The area doesn't constitute the only factor which can explain the level of biodiversity in a region. The species–energy relationship (SER) postulates that energy available to a species assemblage influences its species richness (Storch et al., 2005). Natural ecosystems as self-organizing systems are characterized by dependence on incoming solar radiation which is transformed into the useful energy stored in biomass. The more energy is captured into the mass of plant primary producers, the more species in longer food webs can coexist per unit area. How do humans interfere with the energy flow in ecosystems? Despite escaping the limits of natural production by using fossil fuels, humans still depend on the solar energy for the agricultural production and act as "solar farmers" (Smil 1991). Regular harvest of biomass from both natural and managed ecosystems reduces the energy available in ecosystems for other species. This concept is known as human appropriation of net primary production (HANPP) (Wright 1987, Vitousek et al. 1987, Haberl 1997).

There is some evidence that the human appropriation of net primary production influence species richness. Haberl et al. (2004) analysed the patterns of land-use induced changes in net primary production, biomass harvest and species diversity of plants and invertebrates in an agricultural landscape and found positive relationship between the production which remains in ecosystems after the harvest and biodiversity. The influence of energy availability and environmental production has been observed also for bird assemblages in different parts of the world.

Biodiversity and the disturbance

The disturbance influences biodiversity in a hump-shaped relationship (Rosenzwig, 1995). That means diversity peaks at intermediate disturbance frequencies. Evidence suggest that high biodiversity (at the species level or landscape heterogeneity level) is correlated with the intermediate levels of human impact (D. Vackar, unpublished data). The unmodified pristine reserves and devastated mining areas have both lower levels of biodiversity than the landscape with moderate human density and artificial and managed areas. The intermediate disturbance hypothesis states that moderate levels of disturbance maximize species diversity because competitively dominant species exclude subordinate species at low disturbance, but too much disturbance leads to local extinctions (Dial, Roughgarden, 1998). Humans are raising the diversity of habitat types in the mosaic of different land uses and thus enabling the coexistence of species with different ecological requirements. The inclusion of disturbance has been considered into the EF indicator. Lenzen and Murray (2001) introduced a weighting scheme for the calculation of the Ecological Footprint based on land disturbance. They follow the approach of characterization of ecosystem quality by using land condition and species richness factors. However, the objective disturbance weighting schemes are difficult to develop, given the complexity of biodiversity concept. To examine patterns of biodiversity in regard to land disturbance, I analysed data on land cover and species richness. The land cover and biodiversity groups are outlined in tables 1 and 2, respectively. The area of grouped Corine Land Cover classes was weighted according to the scheme summarized by Lenzen and Murray (2001). The data analysis showed a positive relationship between the weighted land area and species richness. This pattern can be assigned to still intermediate levels of disturbance in Central Europe, although locally the human impact can be pronounced. The long-term coexistence of humans and biodiversity, sample bias and introduction of alien species can be responsible for this trend.

Summary and Conclusions

Undoubtedly, human society exerts significant impact on the natural environment and biodiversity. Exact mechanisms of this impingement remains elusive. The impact is a function of population, consumption and technologies. Human population density and human settlements are highly correlated with species richness and hence with biodiversity threat. Biodiversity is a function of area. The national Biocapacities are positively related to the species richness, measured by the number of endangered species as a proxy. Humans appropriate significant part of the production basis of ecosystems and thus interfere with natural food webs. Colonization of nature and encroachment on natural areas has greatly changed patterns of biodiversity distribution. The biodiversity is linked to the Ecological Footprint mainly through the human population density and hence resource consumption rate, but potentially other factors could be taken into account. Area, energy and disturbance dependence of biodiversity are promising direction in future Footprint-Biodiversity research.

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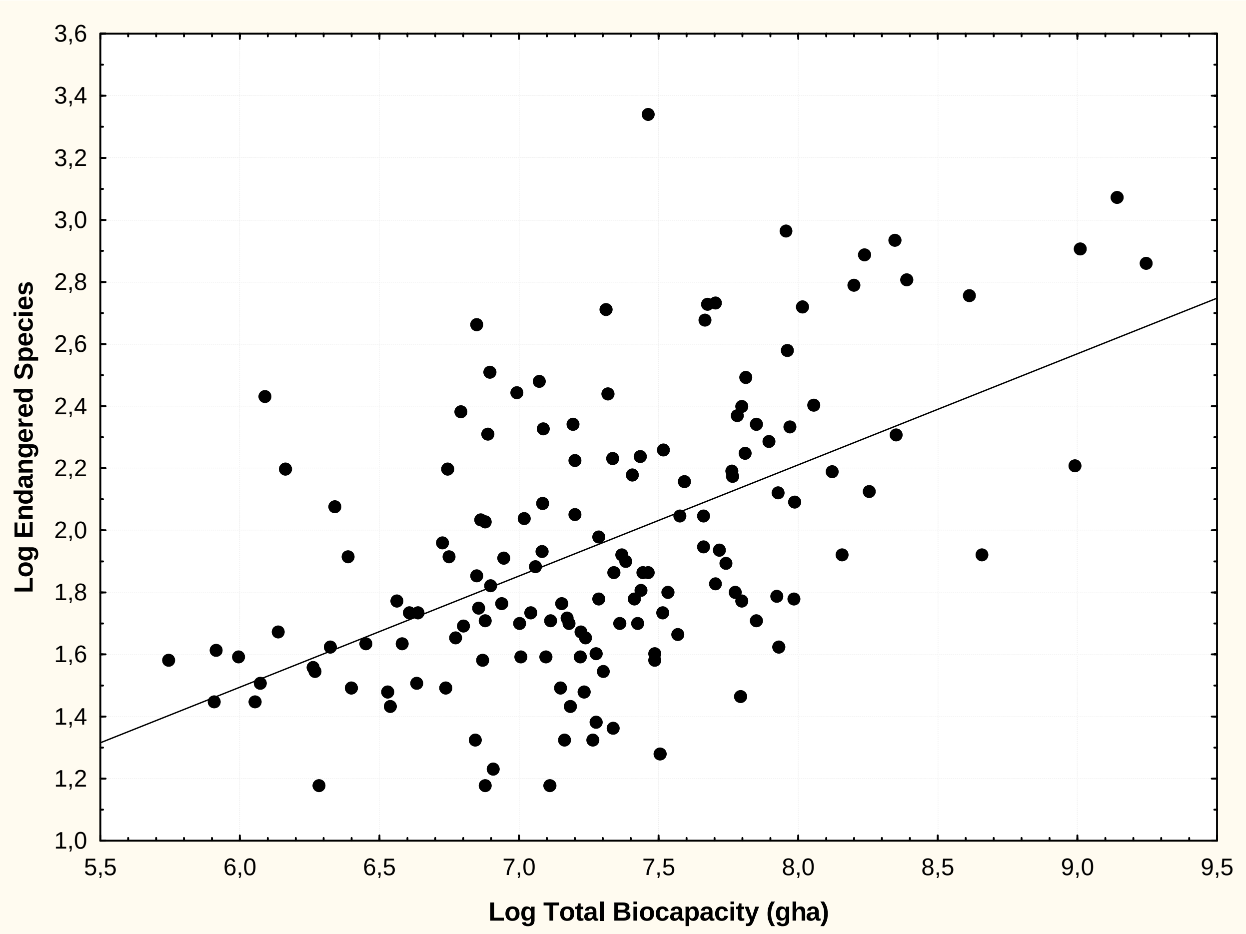

Fig. 1. The positive relationship between the total biocapacity and the number of endangered species, here used as a proxy of total biodiversity.

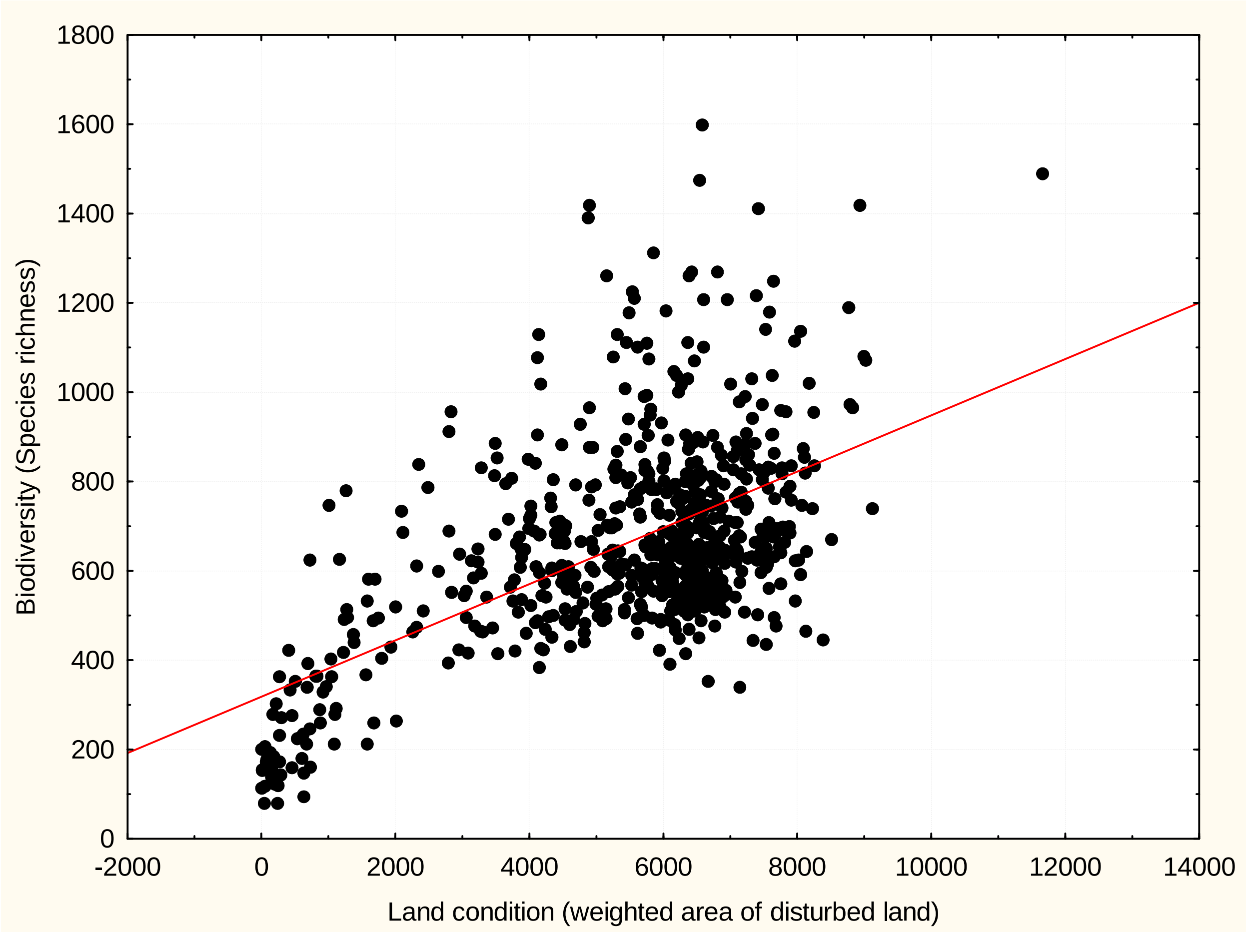

Fig. 2. The relationship between the land disturbance and biodiversity in the Czech Republic.

Table 1. Land cover groups and land condition weights.

CLC group	Weight
1 Artificial surfaces	1
2 Arable land	0,6
3 Permanent crops	0,4
4 Pastures	0,4
5 Mosaic farmland	0,2
6 Standing forests	0,3
7 Transitional woodland & shrub	0,2
8 Natural grassland and heathland	0,0
9 Wetlands	0,0
10 Waterbodies	0,2

Table 2. Biodiversity groups analysed with regard to land disturbance for the area of the Czech Republic.

Species Group
1 Reptiles
2 Amphibians
3 Beetles
4 Butterflies
5 Mammals
6 Spiders
7 Birds
8 Vascular plants