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Ecological Footprint: Implications for biodiversity

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ABSTRACT

In October 2010, world leaders gathered in Nagoya, Japan, for the CBD COP10 and agreed on the adoption of new biodiversity targets and new indicators for the period 2011–2020. This represents a positive development. But given the previous failure in achieving the 2010 biodiversity targets, new approaches to implementation as well as relevant measuring and monitoring systems are needed, for this renewed effort to have lasting success in preserving biodiversity.

The need to adopt a comprehensive approach in monitoring biodiversity clearly emerged and it can be seen in the five strategic goals within which the 2020 Aichi Biodiversity targets are classified. Among them, is the strategic goal A, which aims to *address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society*. The aim of this paper is to describe the role of the Ecological Footprint in tracking human-induced pressures on biodiversity thus providing a synthesis of how the Ecological Footprint tool can contribute to the advancement of conservation science. Information is provided on the main features of the Footprint indicator and its dataset, the ongoing work to improve the methodology as well as the geographical (more than 150 countries covered) and temporal coverage (a period of almost five decades) of the Ecological Footprint accounting tool.

1. Introduction

The material well-being of our societies builds on the biosphere's natural capital including the richness of the species that inhabit the planet. However, as several studies have consistently reported, biodiversity is declining at an unprecedented rate and human pressure on ecosystems is among the contributors to this decline (BIP, 2010; Butchart et al., 2010; EEA, 2010; Ellis et al., 2010; Lenzen et al., 2012; Loh et al., 2005; SCBD, 2010; Walpole et al., 2009; Weinzettel et al., 2013).

Butchart et al. (2010) have concluded that, at global level, leaders' efforts to slow or reverse biodiversity decline have not been sufficient and the CBD 2010 biodiversity Targets (CBD, 2006; SCBD, 2003) have not been met: although responses have increased, they have not managed to counteract growing pressures. Multiple reasons have been identified for the failure to deliver on the 2010 Targets. Although the surface of protected areas and FSC certified forests is increasing, an increasing number of policies are being adopted (nationally and internationally) to tackle the issue of invasive alien species and more funding is invested by national governments and international organizations in biodiversity-related aids, clear biodiversity related targets are still lacking and many policies are improperly implemented (Butchart et al., 2010).

Biodiversity is one of the most striking aspects of our planet; nonetheless knowing how many species inhabit Earth remains enigmatic (Mora et al., 2011). Moreover, a global observation system for monitoring biodiversity changes does not exist yet (Pereira et al., 2012) and consistency is lacking at national and regional level in monitoring and sharing frameworks (Pereira et al., 2013). Acknowledging the complexity of developing a global observation system – about 100 indicators have been proposed for the 2020 Aichi Biodiversity Targets (CBD, 2010) – Pereira et al. (2013) have proposed an EBV (Essential Biodiversity Variables) process as starting point for global biodiversity monitoring programs. Undoubtedly a step in the right direction, such EBV process is still lacking a proper focus on pressures on ecosystems and threats to biodiversity as well as measures of the economic significance of biodiversity in decision-making processes. Of the five strategic goals of the 2020 Aichi Biodiversity Targets (CBD, 2010), strategic goal A – "*Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society*" – is by far the least developed one with no agreement about what to monitor and how to monitor it.

The extent of human induced pressures on ecosystems and their potentially debilitating consequences for both the planet's health and society's social and economic stability are hardly

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informing the main political and economic decisions. Trends reported in Butchart et al. (2010) for five selected parameters (Ecological Footprint, nitrogen deposition, alien species, fish stock overexploitation and climate impact) indicate that human-induced pressures have increased over the last few decades. Findings from Rockström et al. (2009) suggest that, because of such increased human pressure, mankind is likely to be already beyond safe operating limits in key planetary systems. The accumulation of human pressure is fundamental to many environmental issues and world leaders face the challenge of selecting appropriate policies and investments to prevent further detrimental effects (Bauler, 2012; Heink and Kowarik, 2010; Moldan et al., 2012).

According to a recent study (McCarthy et al., 2012), reducing the extinction risk of threatened species could cost up to $US 4.76 billion a year, while effectively managing all sites of global conservation significance would cost approximately $US 76.1 billion per year. Efforts to conserve biodiversity have been historically directed towards the protection of habitats and species. However, although fundamental in conservation efforts (Butchart et al., 2012) and potentially capable to supply more regulating services than threatened habitats (Maes et al., 2012), protected areas (PA) may no longer be sufficient in reducing the risk of species' extinction given how fast human pressure is growing. Measuring and monitoring the drivers of human pressure, and thus of biodiversity loss, is therefore necessary and efforts need to be substantially strengthened to address the loss of biodiversity at planetary level for 2020 Aichi Biodiversity Targets to come alive.

A broad range of empirical measurements exists that can be used to identify the driving forces behind impacts and select policies to reduce them while maintaining economic and societal well-being (e.g., Chapin et al., 2009). One of them is the Ecological Footprint, an accounting system for ecosystem services described in this article.

As human demands upon the Earth's ecosystems rapidly increase (Goudie, 1981; Haberl, 2006; Nelson et al., 2006; Rockström et al., 2009), the future ability of the biosphere to provide for humanity and the many other species is being degraded. Barnosky et al. (2012) have argued that a planetary-scale critical transition is approaching because of the many human pressures, and that tools are needed to detect early warning signs and forecast the consequences of such pressures on ecosystems. The Ecological Footprint (Wackernagel et al., 2002) can be one of such tools; however, it is just one of the many pressure indicators in need to be adopted and the variables it measures are just some of those one need to consider when looking at the overall pressure mankind poses on the planet's ecological assets.

The aim of this paper is thus to clearly describe the main research question and the key features of the Ecological Footprint methodology and explain how this metric links to five key mechanisms of biodiversity loss. By providing results about country trends, and giving examples of how Footprint accounts track global (or indirect) pressures on biodiversity, the paper outlines how this tool can be used to complement measures of ecosystem-specific direct impacts on biodiversity.

2. Methodology

2.1. Ecological Footprint and biocapacity: an overview

Pursuing a sustainable approach to human development – which includes avoiding habitats and species loss – requires better understanding the choices before us. For this, policy and decision makers need the knowledge and tools to manage the Earth's ecosystems and ecological assets as well as the pressure human activities pose on them. The Ecological Footprint methodology (Wackernagel et al., 2002) offers a way to measure one key aspect defining the resource dimension of sustainable development. It provides an accounting system that tracks how much of the planet's regenerative capacity humans demand to produce the resources and ecological services for their daily lives and compares that to how much regenerative capacity they have available from existing ecological assets. This accounting tool can be applied globally and at the regional and country level and gives insight on the above by means of two indicators:

- On the demand side, the *Ecological Footprint* measures the biologically productive land and sea area – the ecological assets – that a population requires to produce the renewable resources and ecological services it uses.
- On the supply side, *biocapacity* tracks the ecological assets available in countries, regions or at the global level and their capacity to produce renewable resources and ecological services.

Both Ecological Footprint and biocapacity results are expressed in a globally comparable, standardized unit called "global hectare" (gha) – a hectare of biologically productive land or sea area with world average bioproductivity in a given year (Galli et al., 2007; Monfreda et al., 2004).

Although unable to track every human-related pressure on the biosphere, the Ecological Footprint attempts to capture all demands on the biosphere that compete for space. Demand refers to usage of biologically productive land and sea areas that generate the renewable resources and ecological services that humans demand (Fig. 1). By measuring the demands that compete for biologically productive space, the biocapacity and Ecological Footprint indicators focus on the biomass-based flows of the ecosystems' provisioning services and the waste uptake of its regulating services. Examples of the services quantified by Ecological Footprint accounts and the ecosystem-types providing them include: cropland for the provision of plant-based food and fiber products; grazing land and cropland for animal products; fishing grounds (marine and inland) for fish products; forests for timber and other forest products as well as for sequestration of waste (CO_2, primarily from fossil fuel burning) thus regulating the climate. Built-up surface for shelter and other urban infrastructure is also tracked (Borucke et al., 2013).

A country's Ecological Footprint of consumption (EF_C) is derived by tracking the ecological assets demanded to absorb its waste and to generate all the commodities it produces, plus imports minus exports. It is calculated as shown in equation 1 (see Borucke et al., 2013).

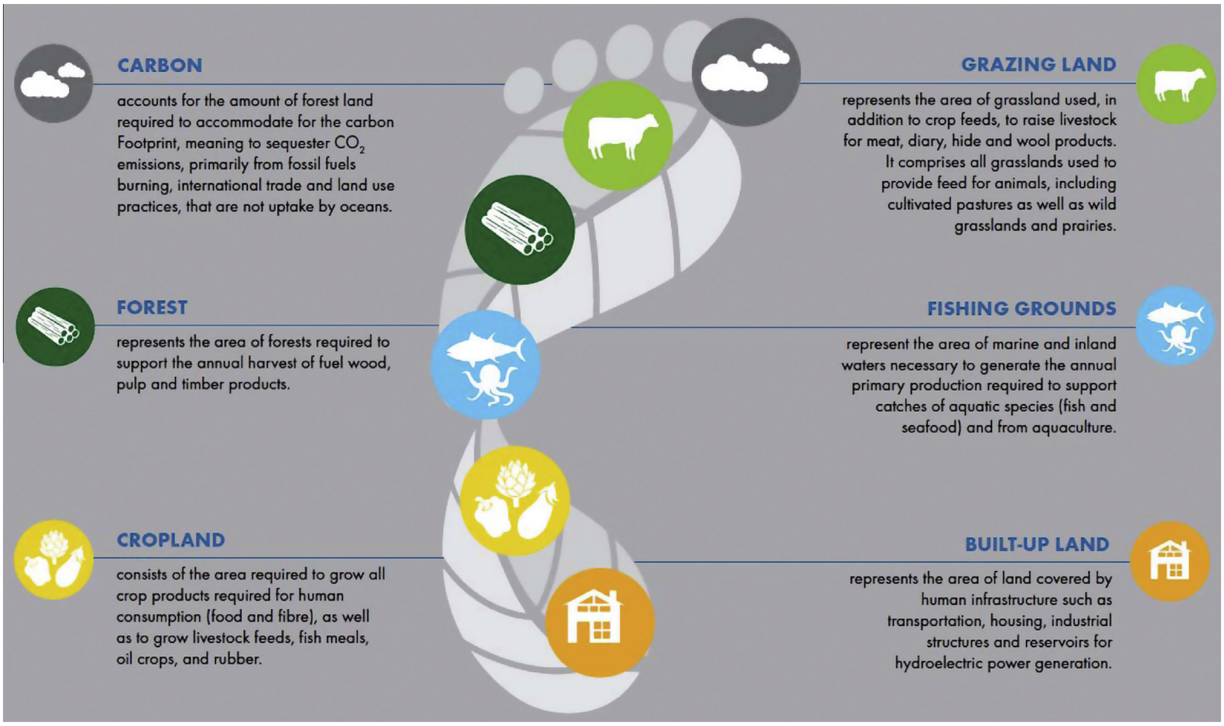
$$\mathrm{EF_C} = \mathrm{EF_P} + \mathrm{EF_I} - \mathrm{EF_E} \tag{1}$$

where EF_P is the Ecological Footprint of production and EF_I and EF_E are the Footprints embodied in imported and exported commodity flows, respectively. Since Ecological Footprints are calculated in global hectares, the Ecological Footprint (EF) of each single product *i*, irrespective of whether it is locally produced, imported or exported, is calculated as in:

$$\mathrm{EF} = \frac{P_i}{Y_{W,i}} \cdot \mathrm{EQF}_i \tag{2}$$

where *P* is the amount of each primary product *i* that is harvested (or carbon dioxide emitted) in the nation; $Y_{W,i}$ is the annual world-average yield for the production of commodity *i* (or its carbon uptake capacity in cases where *P* is CO_2); and EQF_i is the equivalence factor for the land use type producing products *i*.

The Ecological Footprint of consumption (EF_C) indicates the demand for biocapacity by a country's inhabitants while the Ecological Footprint of production (EF_P) indicates the demand for


CARBON

accounts for the amount of forest land required to accommodate for the carbon Footprint, meaning to sequester CO_2 emissions, primarily from fossil fuels burning, international trade and land use practices, that are not uptake by oceans.

FOREST

represents the area of forests required to support the annual harvest of fuel wood, pulp and timber products.

CROPLAND

consists of the area required to grow all crop products required for human consumption (food and fibre), as well as to grow livestock feeds, fish meals, oil crops, and rubber.

GRAZING LAND

represents the area of grassland used, in addition to crop feeds, to raise livestock for meat, diary, hide and wool products. It comprises all grasslands used to provide feed for animals, including cultivated pastures as well as wild grasslands and prairies.

FISHING GROUNDS

represent the area of marine and inland waters necessary to generate the annual primary production required to support catches of aquatic species (fish and seafood) and from aquaculture.

BUILT-UP LAND

represents the area of land covered by human infrastructure such as transportation, housing, industrial structures and reservoirs for hydroelectric power generation.

Fig. 1. Land use categories comprising the Ecological Footprint (see Borucke et al. (2013) for additional information on the calculation methodology for each of these categories). Land types such as cropland, grazing land, forest and fishing ground refer to the demand for provisioning services while the carbon uptake land refers to the demand for the regulating service of sequestering CO_2. *Source*: Maddox design (2012).

biocapacity resulting from production processes within a given geographic area, such as a country or region. The Ecological Footprint of imports (EF_I) and exports (EF_E) indicate the use of biocapacity within international trade: if the Ecological Footprint embodied in exports is higher than that of imports, then a country is a net exporter of renewable resources and ecological services. Conversely, a country whose Footprint embodied in imports is higher than that embodied in exports depends on the renewable resources and ecological services generated by ecological assets from outside its geographical boundaries.

While the Ecological Footprint quantifies human demand, biocapacity acts as an ecological benchmark and quantifies nature's ability to meet this demand. Biocapacity is calculated as in Eq. (3) and, for each country, it provides an assessment of that country ecological assets' capacity to produce renewable resources and ecological services.

$$\mathrm{BC} = \sum_i \mathrm{A}_{N,i} \cdot \mathrm{YF}_{N,i} \cdot \mathrm{EQF}_i \tag{3}$$

where $A_{N,i}$ is the bioproductive area that is available for the production of each product i at the country level, $YF_{N,i}$ is the country-specific yield factor for the land producing products i, and EQF_i is the equivalence factor for the land use type producing each product i. A detailed explanation of Ecological Footprint and biocapacity calculations can be found in Borucke et al. (2013).

The main aim of the Ecological Footprint methodology is to promote recognition of the Earth's ecological limits, and in this way help safeguarding the ecosystems' preconditions (healthy forests, clean waters, clean air, fertile soils, biodiversity, etc.) and life-supporting services that enable the biosphere to provide for us all in the long term. The ambition lying behind Ecological Footprint accounts is thus to provide managerial and monitoring capacity for assessing and dealing with biocapacity, its biophysical constraints, human induced environmental impacts and the pressure human activities generate on the Earth's ecosystems.

2.2. National Footprint Accounts: Dataset description & coverage

Ecological Footprint and biocapacity can be calculated at scales ranging from single products, to cities and regions, to countries and the world as a whole. However, nation-level Ecological Footprint assessments – known as National Footprint Accounts (NFA) – are often regarded as the most complete (Kitzes et al., 2009). The first systematic attempt to calculate the Ecological Footprint and biocapacity of nations began in 1997 (Wackernagel et al., 1997), while the most recent edition of the NFA has been released in 2011 (Global Footprint Network, 2011).

The NFA 2011 Edition calculates and reports Ecological Footprint and biocapacity values for approximately 160 countries, as well as global totals, from 1961 to 2008 (Global Footprint Network, 2011). To perform such calculation, approximately 60 million underlying source data points from approximately 30 data sets are used. The calculations in the NFA are based primarily on data sets from UN agencies or affiliated organizations such as the Food and Agriculture Organization of the United Nations (FAOSTAT, 2011), the UN Statistics Division (UN Commodity Trade Statistics Database – UN Comtrade, 2011), and the International Energy Agency (IEA, 2011). Other data sources include studies in peer-reviewed journals and thematic collections. The complete list of source data sets, drawn from Borucke et al. (2013), is summarized in Table 1.

Most raw data is obtained in CSV (comma separated value) or similar flat text file format. Some data arrangement and supporting calculations are performed using Microsoft Excel, after which raw data and intermediate results are stored in a MySQL database. Further data pre-processing – such as light data cleaning – is then performed by executing scripts within the database environment. In

Table 1
Input data to the Ecological Footprint and biocapacity calculation. Approximately 61 million data points are used in the National Footprint Accounts 2011 Edition (6000 data points per country and year). *Source*: Borucke et al. (2013).

Dataset	Source	Description
Production of primary agricultural products	FAO ProdSTAT	Physical quantities (tonnes) of primary products produced in each of the considered countries
Production of crop-based feeds used to feed animals	Feed from general marketed crops data is directly drawn from the SUA/FBS from FAOSTAT Data on crops grown specifically for fodder is drawn directly from the FAO ProdSTAT	Physical quantities (tonnes) of feeds, by type of crops, available to feed livestock
Production of seeds	Data on crops used as seeds is calculated by Global Footprint Network based on data from the FAO ProdSTAT	Physical quantities (tonnes) of seed
Import and Export of primary and derived agricultural and livestock products	FAO TradeSTAT	Physical quantities (tonnes) of products imported and exported by each of the considered countries
Import and Export of non-agricultural commodities	COMTRADE	Physical quantities (kg) of products imported and exported by each of the considered countries
Livestock crop consumption	Calculated by Global Footprint Network based upon the following datasets: • FAO Production for primary Livestock • Haberl et al. (2007)	Data on crop-based feed for livestock (tonnes of dry matter per year), split into different crop categories
Production of primary forestry products as well as import and export of primary and derived forestry products	FAO ForeSTAT	Physical quantities (tonnes and m^3) of products (timber and wood fuel) produced, imported and exported by each country
Production of primary fishery products as well as import and export of primary and derived fishery products	FAO FishSTAT	Physical quantities (tonnes) of marine and inland fish species landed as well as import and export of fish commodities
Carbon dioxide emissions by sector	International Energy Agency (IEA)	Total amounts of CO_2 emitted by each sector of a country's economy
Built-up/infrastructure areas	A combination of data sources is used, in the following order of preference: 1. CORINE Land Cover 2. FAO ResourceSTAT 3. Global Agro-Ecological Zones (GAEZ) Model 4. Global Land Cover (GLC) 2000 5. Global Land Use Database, SAGE, University of Wisconsin	Built-up areas by infrastructure type and country. Except for data drawn from CORINE for European countries, all other data sources only provide total area values
Cropland yields	FAO ProdSTAT	World average yield for 164 primary crop products
National yield factors for cropland	Calculated by Global Footprint Network based on cropland yields and country specific unharvested percentages	Country specific yield factors for cropland
Grazing land yields	Monfreda, C., personal communication, 2008. SAGE, University of Wisconsin, Madison	World average yield for grass production. It represents the average above-ground edible net primary production for grassland available for consumption by ruminants
Fish yields	Calculated by Global Footprint Network based on several data sources including: • Sustainable catch value (Gulland, 1971) • Trophic levels of fish species (Fishbase Database available at www.fishbase.org) • Data on discard factors, efficiency transfer, and carbon content of fish per tonne wet weight (Pauly and Christensen, 1995)	World-average yields for fish species. They are based on the annual marine primary production equivalent.
Forest yields	World average forest yield calculated by Global Footprint Network based on national Net Annual Increment (NAI) of biomass. NAI data is drawn from two sources: • Temperate and Boreal Forest Resource Assessment – TBFRA (UNECE and FAO, 2000) • Global Fiber Supply Model – GFSM (FAO, 1998)	World average forest yield. It is based on the forests' Net Annual Increment of biomass NAI is defined as the average annual volume over a given reference period of gross increment less that of neutral losses on all trees to a minimum diameter of 0 cm (d.b.h.)
Carbon Uptake land yield	Calculated by Global Footprint Network based on data on terrestrial carbon sequestration (IPCC, 2006) and the ocean sequestration percentage (Khatiwala et al., 2009) Further details can be found in Borucke et al. (2013)	World average carbon uptake capacity. Though different ecosystems have the capacity to sequester CO_2, carbon uptake land is currently assumed to be forest land only by the Ecological Footprint methodology
Equivalence Factors (EQF)	Calculated by Global Footprint Network based on data on land cover and agricultural suitability Data on agricultural suitability is obtained from the Global Agro-Ecological Zones (GAEZ) model (FAO and IIASA, 2000) Land cover data drawn from the FAO ResourceSTAT database	EQF for crop, grazing, forest and marine land. Based upon the suitability of land as measured by the Global Agro-Ecological Zones model

calculating each country's Ecological Footprint, this database is queried for the appropriate country and year values – via custom-built data managing software – and the resulting information are organized in 107 interconnected worksheets in a Microsoft Excel workbook, which constitutes the NFA Excel workbook for that specific country in the given year. Results for each country and year are then stored into MySQL and available to be distributed to users upon request. There is no public access to the Global Footprint Network's internally maintained database while National Footprint Accounts Licenses and the main country results and time trend graphs are available on Global Footprint Network's website. Input data used by Global Footprint Network in calculating the NFAs

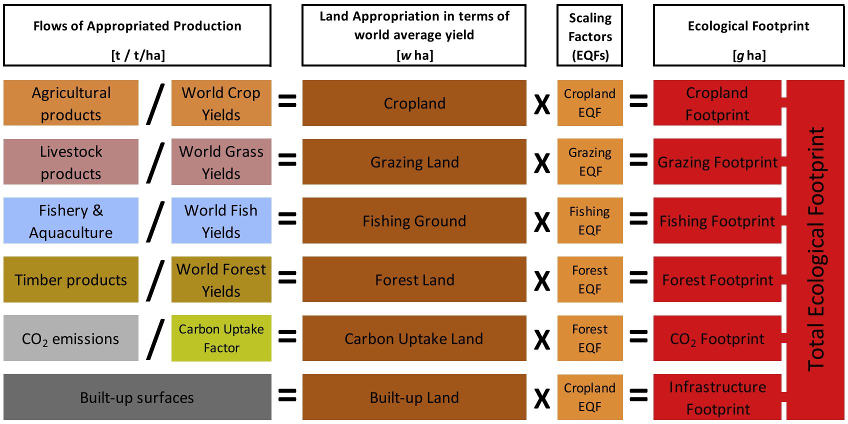


Fig. 2. Ecological Footprint accounting framework. *Source*: adapted from Borucke et al. (2013).

can be accessed by directly contacting the respective databases' custodian institutions (e.g., FAO, IEA, etc.), though a subscription might be required.

National Ecological Footprint of consumption results are reported at the level of each individual land type, or aggregated into a single number (Fig. 2) – the latter being the most commonly used reporting format. Normalizing factors, referred as the yield factor and equivalence factor, are used to scale the contribution of each single land type in a unit that is globally comparable. As a result, values can be added up into an aggregate number (see Galli et al., 2007; Borucke et al., 2013). Aggregating results into a single value allows monitoring the combined pressure that anthropogenic activities pose on the Earth's Ecosystems.

By definition, any indicator is a simplification of a much more complex reality and this holds true for the Ecological Footprint as well. Details on the Ecological Footprint's main features (i.e., scientific robustness, research question, policy usefulness, temporal and spatial coverage, etc.) are reported in Table 2.

2.3. National Footprint Accounts: a work in progress

National Footprint Accounts are a work in progress and are maintained and updated annually by Global Footprint Network through a continuous search for, and use of, data sets that are more comprehensive and reliable as well as by revising and updating the underlying methodology and the calculation process. Each time methodological improvements are implemented and a new edition of the National Footprint Accounts is released, Ecological Footprint and biocapacity values are back calculated from the most recent year in order to ensure consistency across all years. Global Footprint Network considers the current National Footprint Accounts as evidence that biocapacity accounting is possible, with far more potential for accuracy and detail (Global Footprint Network, 2010).

Global Footprint Network's review and improvements efforts aim at improving the way we understand and measure human pressure on ecosystems and they start with transparency: the method is published on the Network's website and in academic journals (e.g., Borucke et al., 2013; Ewing et al., 2010; Kitzes et al., 2007; Monfreda et al., 2004; Wackernagel et al., 2002). In addition, Global Footprint Network directly invites national governments (and their respective agencies) to verify the assessments – including suggesting improvements. About 12 such assessments have been completed or are still under way.[1] Completed ones include that from the European Parliament (ECOTEC, 2001), Switzerland (von Stokar et al., 2006), Luxembourg (Hild et al., 2010), United Arab Emirates (Abdullatif and Alam, 2011), European Commission (DG Environment, 2008), Japan (see for details WWF Japan, 2012:p49), and the UK (RPA, 2007).

3. Past trends, current situation and future projections

The National Footprint Accounts attempt to track all competing demands for biologically productive surfaces. The most recent edition of the NFAs (Global Footprint Network, 2011) indicate that, during the period 1961–2008, humanity's overall Ecological Footprint[2] has increased by a factor of 2.5 from 7.2 to 18.2 billion global hectares (gha). At the same time, global biocapacity has also increased by a factor of 1.2 from 9.8 to 12 billion gha because of the increased availability of land suitable for agriculture and the increase in agricultural yields (Foley et al., 2011). However, the increase in the supply side (of resource and services) has not been able to counterbalance that on the demand side. As a result, in 2008 humanity demanded the resources and services of 1.5 planets worth of ecological assets (Fig. 3): in other words, human activities were outstripping nature's regenerative capacity by 50%. The increase in global demands were most prominent for the carbon Footprint (increased by a factor of 3.8 due to the growing use of fossil fuels, electricity and energy intensive commodities), the fish Footprint (by a factor of 2.4) and agricultural Footprint (by a factor of 2.3).

Ecological Footprint and biocapacity can also be compared at the national level to identify the ecosystems on which human production activities are exerting the highest pressure as well as the countries whose consumption patterns are driving such pressure. While most countries' demand for consumption did not overload their own ecosystems in 1961 (EF < BC), 83% of the world's population now live in countries that use more biocapacity to support production activities than they have available within their boundaries. The deficit is covered through the overexploitation of domestic natural capital stocks (e.g., through overharvesting and overfishing), net import of resources, and the use of the global commons (for instance by emitting CO_2 from fossil fuel into the atmosphere).

Both the Footprint of consumption and the Footprint of production can be compared against biocapacity, revealing distinct realities: the Footprint of consumption identifies the amount of

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[1] Detailed info on reviews by national governments is listed on Global Footprint Network's website at www.footprintnetwork.org/reviews.

[2] At the global level, the Ecological Footprint of consumption activities and that of production activities are identical as no trade is taking place with other planets. As such, the global trends reported in here indicate an actual increase in the overall pressure posed on the Earth's various ecosystems.

Table 2
Key features of the ''Ecological Footprint'' accounting tool.

Research question	Main message	Unit of measure	Coverage	Policy usefulness
The amount of the biosphere's regenerative capacity that is directly and indirectly (i.e. embodied in trade) used by humans (or Ecological Footprint) compared with how much is available (or biocapacity), at both local and global scale	To promote recognition of ecological limits and safeguard the ecosystems' life-supporting services enabling the biosphere to support mankind in the long term	Global hectares (gha) of bioproductive land. *Note*: gha is not a measure of area but rather of the ecological production associated with an area	Temporally explicit and multi-dimensional indicator; it can be applied to single products, cities, regions, nations and the whole biosphere	Measures 'overshoot' and identifies the pressures that humanity is placing to various ecosystem services
		Results can also be expressed in actual physical hectares	Data are available for nearly 240 nations for the period 1961–2008; data for only about 150 nations are consistently published For each nation and each land type, Ecological Footprint of production, import, export and consumption activities are available	Monitors societies' progresses towards minimum sustainability criteria (demand $\leqslant$ supply) Monitors the effectiveness of established resource use and resource efficiency policies Indirectly tracks pressure on biodiversity Tracks the global distribution of supply of, and demand for, ecological assets

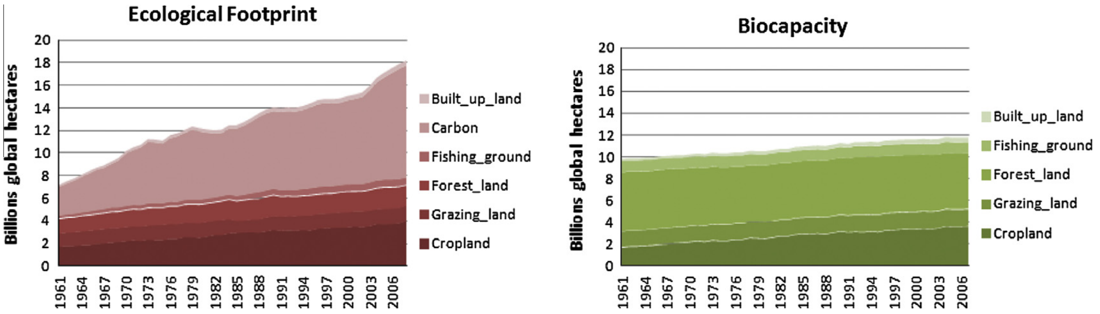

Fig. 3. Humanity's total Ecological Footprint (left) and biocapacity (right), by land type, 1961–2008. Ecological Footprint started exceeding global biocapacity and humanity entered in a global overshoot situation in the early '70s. Human demands for forest products and carbon uptake capacity are both competing for forest land. However, when a forest is used for products, CO_2 is released again in the atmosphere; as such, only legally protected forests with a commitment to long term storage of carbon can truly be counted as available uptake areas. Global Footprint Network has not yet identified reliable global data sets on how much of the forest areas are legally protected and dedicated to long-term carbon uptake. For this reason, current NFAs do not include a carbon uptake category within the biocapacity calculation.

biocapacity needed to supply for what the residents of the country ultimately consume. It gives an indication of the countries whose consumption patterns drive global displacement of human-induced pressure (Fig. 4, top map). Conversely, the Footprint of production refers to how much demand is put on local ecosystems through the country's productive economic activities. It therefore indicates where the displacement of human-induced pressures is taking place (Fig. 4, bottom map). As the maps show, most of the countries that are characterized by a Footprint of consumption activities higher than the local biocapacity, also have a Footprint of production higher than the local biocapacity. There are some exceptions to this: for instance, to sustain the consumption needs of its residents Norway demands less resources and services than those its ecosystems can generate. However, the comparison between Footprint of production activities and local biocapacity is indicating that Norway is extracting from its ecosystems more resources and services than those that would be annually generated. Consumption in other countries is therefore driving biocapacity extraction in Norway. Conversely, Ecuador's consumption Footprint higher than biocapacity is not fueled by an overharvesting of local biocapacity but rather through a net import of biocapacity from other countries of the world.

Furthermore, a country's Footprint of production for forest products, for example, may be lower than what forests in that country can regenerate. This means the local forest is not overused. But residents may buy additional forest product from abroad, to an extent that their net demand exceeds what their own forests can supply (see also Section 4.2). In this case, the country would run a biocapacity deficit without local depletion, but displacing pressure on ecosystems elsewhere.

If we lived in a world where countries consumed only domestic goods, the distinction between consumption-based and production-based accounting would be unnecessary. But we live in a highly globalized world with large volumes of trade and both production- and consumption-based analyses thus need to be used to fully understand the human drivers of biodiversity loss and take actions to reverse them (Galli et al., 2012). Fig. 5 provides the map of net biocapacity importing and exporting countries in 2008.

Results indicate that the top five countries in terms of net export of biocapacity are Canada, Argentina, Brazil, Australia and Indonesia: these five countries alone are net exporters to the world of approximately 0.5 billion global hectares worth of renewable resources and ecological services. More precisely, Canada's main net export is biocapacity from forest ecosystems, while biocapacity

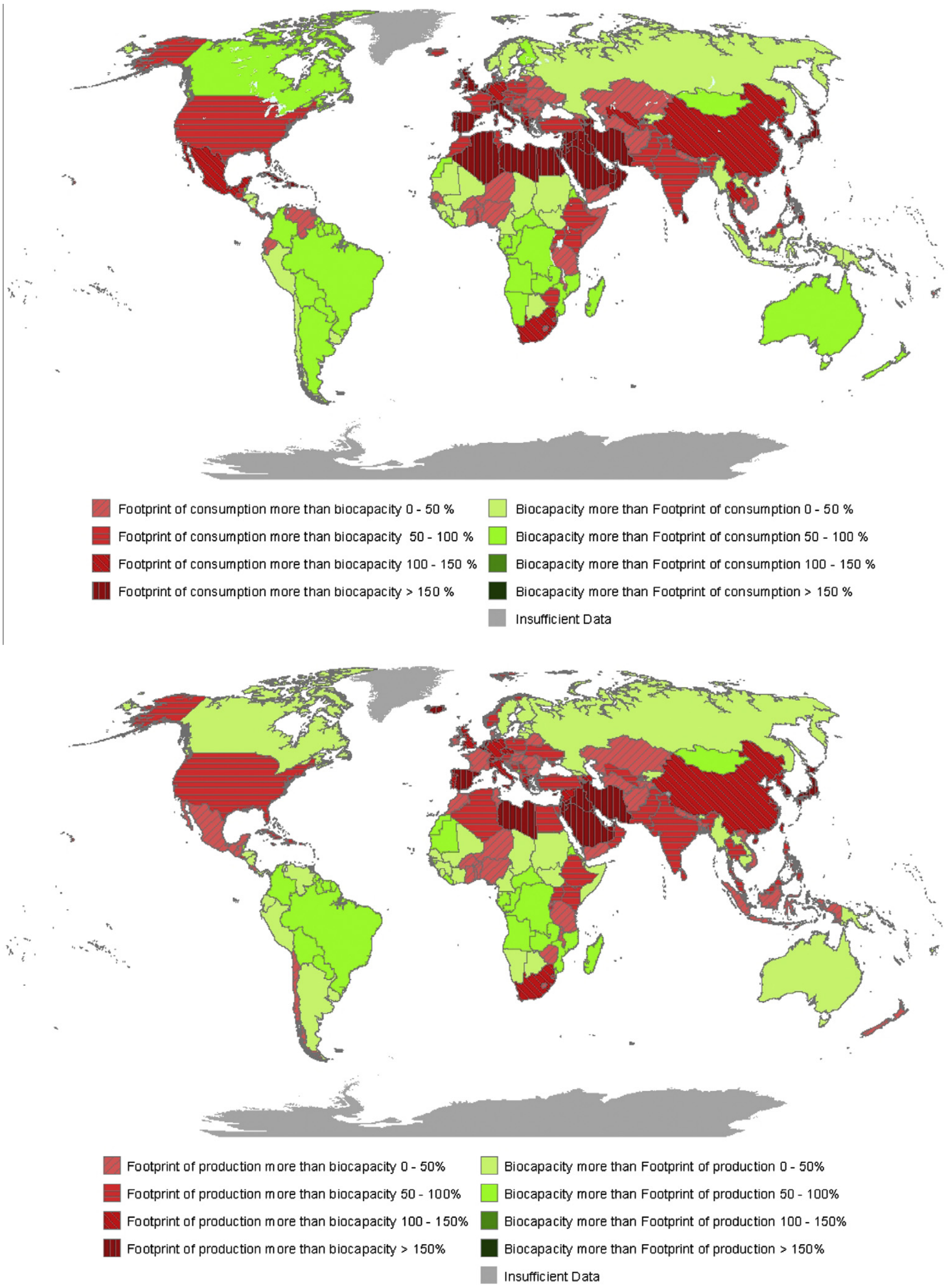

Fig. 4. Ecological Footprint (EF) vs. biocapacity (BC) for world countries in 2008. In the top map (EF_C vs. BC), biocapacity reserve (green) is defined as a domestic Ecological Footprint of consumption less than domestic biocapacity and biocapacity deficit (red) as an Ecological Footprint of consumption greater than domestic biocapacity. In the bottom map (EF_P vs. BC), biocapacity reminder (green) is defined as a domestic Ecological Footprint of production less than domestic biocapacity and ecological overshoot (red) as an Ecological Footprint of production greater than domestic biocapacity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

from agricultural ecosystems makes up for the biggest part of Argentina and Brazil next biocapacity exports (see also Section 4.2). The top five countries in terms of net import of biocapacity are Japan, Mexico, Italy, United Kingdom and Egypt (for a cumulative net import of nearly 0.6 billion gha worth of resources and ecological services). Japan main import, in net terms, is cropland biocapacity: approximately 50 million global hectares worth of cropland biocapacity in 2008.

Many studies argue that the increase in human consumption levels that we have witnessed in the last decades is placing unprecedented demands on the biosphere's provisioning services and is contributing to the degradation of land and water resources, the decline of biodiversity and the alteration of the global climate (Barnosky et al., 2012; Butchart et al., 2010; Foley et al., 2011; Halpern et al., 2012; Rulli et al., 2013; Weinzettel et al., 2013) to the extent that we might be already beyond safe operating limits in key planetary systems (Rockström et al., 2009).

Kitzes et al. (2008) have also argued that entering into a global overshoot situation about three decades ago has resulted in the accumulation of an historical ecological debt of nearly 2.5 years worth of Earth's regenerative capacity. With one planet year being equal to the annual capacity of the Earth's ecological assets to pro-

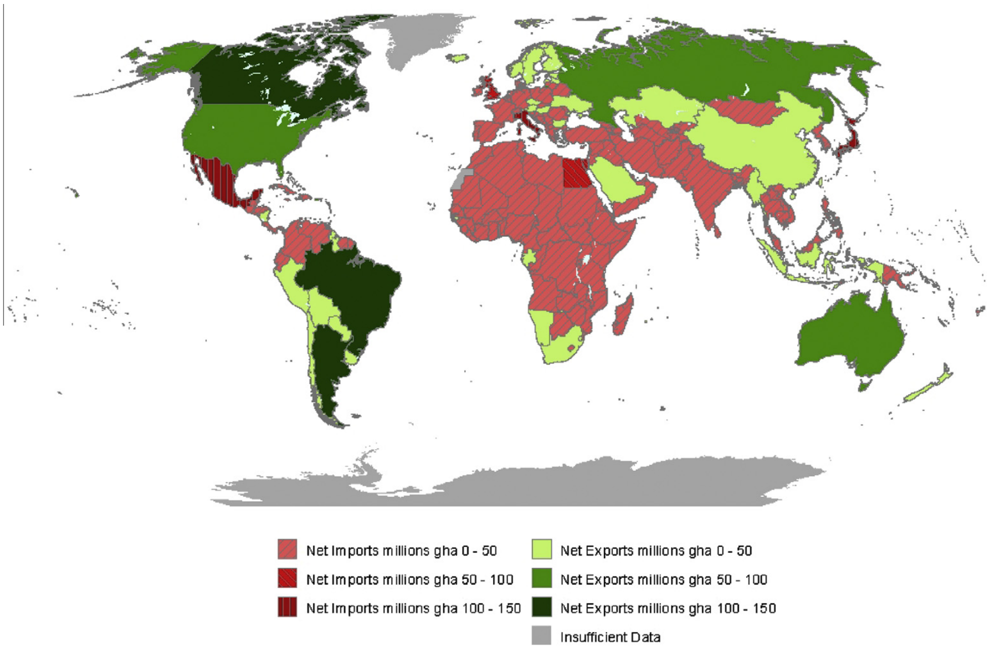

Fig. 5. Net biocapacity importing (red) and exporting (green) countries in 2008. Net importing countries import more biocapacity than they export and have an Ecological Footprint of consumption greater than their Ecological Footprint of production. The opposite is true for net exporting countries. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

duce human-useful ecosystem services, this means that, if all human demand on the biosphere were to cease today, the Earth would take at least 2.5 years to bring ecological assets back up to pre-overshoot levels if overuse were fully reversible. Moreover, a recent study by Moore et al. (2012) has found that, besides contributing to the ecological debt's accumulation, overshoot is also unlikely to decrease in the coming decades: under widely accepted consumption and population projections and a business as usual path, humanity will likely demand the equivalent of 2.6 planet's worth of ecological resources and services by 2050. This situation, in turn, is likely to exacerbate the human induced pressure the Earth's ecosystems and the species that inhabit them are exposed to. Under such scenario, achieving an efficient and productive management of the Earth's ecosystems while satisfying the needs of a growing population and preserving biodiversity is a global challenge. Complex trade-offs exist between human well-being and biodiversity conservation goals, and between conservation and other economic, political and social agendas (McShane et al., 2011).

4. Discussion

4.1. Monitoring mechanisms of biodiversity loss through the Ecological Footprint

Direct anthropogenic threats to biodiversity can be grouped under five headings: (1) habitat loss, fragmentation or change, especially due to agriculture, large-scale forestry, and human infrastructure; (2) overexploitation of species, especially due to fishing and hunting, but also overuse of ecosystem services leading to above mentioned habitat loss; (3) pollution that affects the health of species; (4) spread of invasive species or genes outcompeting endogenous species and (5) climate change shifting habitat to an extent that it is no longer suitable for the threatened species (see also MEA, 2005 and WWF et al., 2008).

Ultimately, all five of these threats stem from human demands on the biosphere – the extraction and harvest of natural resources for human consumption, such as food, fiber, energy or materials, as well as the disposal of associated waste products – or the disruption of natural ecosystems by towns, cities and infrastructure. Natural habitat is lost, altered or fragmented through its conversion for cultivation, grazing, aquaculture, forestry (including plantations) and industrial or urban use (DeFries et al., 2004, 2010; Phalan et al., 2011; Weinzettel et al., 2013). River systems are dammed and altered for irrigation, hydropower or flow regulation. Even marine ecosystems, particularly the seabed, are physically degraded by trawling, construction and extractive industries.

Overexploitation of wild species populations is the result of harvesting plants and hunting animals for food, materials, trophies or medicine, at a rate above the reproductive capacity of the population. Overfishing has been the dominant threat to marine biodiversity, and it has devastated many commercial fish stocks (Halpern et al., 2012; Swartz et al., 2010; Butchart et al., 2010). Overexploitation is also a serious threat to many terrestrial species, particularly tropical forest mammals hunted for meat. Overharvesting of timber and fuelwood has led to loss of forests and their associated plant and animal populations, also by shifting species composition. All these factors are part of Ecological Footprint accounting.

Moreover, globalization with rapid growth in international trade flows (in commodities, services and people) has become an ever more potent vector for the spread of alien species and diseases (Essl et al., 2011; Pyšek et al., 2010). Invasive species, introduced deliberately or inadvertently to one part of the world from another mainly through trade – and which become competitors, predators or parasites of indigenous species – are responsible for declines in many native species populations.

Pollution is another important cause of biodiversity loss, particularly in aquatic ecosystems. Excess nutrient loading due to the increasing use of nitrogen and phosphorous fertilizers in agriculture causes eutrophication and oxygen depletion (Cassman et al., 2002; Galloway et al., 2003). Toxic chemical pollution can weaken the health of species populations in a number of ways. Such pollution arises from pesticide use in farming, gardening or aquaculture, from wastes emitted in industrial processes and from mining wastes. The increasing carbon dioxide concentration in the atmosphere is causing acidification of the oceans, which is likely to have widespread effects, particularly on shell- and reef-building organisms. Most pollution flows are not tracked in current National Footprint Accounts. Many tend to be outcomes of higher level of human activities, even though some specific pollution flow can be significantly reduced with the use of environmental technologies such as filters or treatment plants.

A slower, but potentially large threat to biodiversity over the coming decades is climate change. Early impacts have been felt in polar regions and mountain areas, where habitat runs out of space as well as in coastal and marine ecosystems, such as coral reefs. These impacts are not immediate and spread across the globe, susceptible to changing temperature or weather patterns. This makes them difficult to manage since cause and effect are far removed in time and space. The carbon emission is part of Ecological Footprint Accounts.

Many of the above threats or pressures are the effect of more distant, indirect drivers as they stem from the human demands for food, water, energy and materials. These demands can be considered in terms of the production and consumption of agricultural crops, meat and dairy products, fish and seafood, timber and paper, energy, transport and land for towns, cities and infrastructure, and are captured by Ecological Footprint Accounts. When people catch more fish than fishing grounds can regenerate, fisheries eventually collapse; when people harvest more timber than forests can re-grow, they advance deforestation; when people emit more CO_2 than the biosphere can absorb, CO_2 accumulates in the atmosphere and contributes to global warming. The overuse of these and other ecosystem services constitutes an ecological deficit or, when taking place at planetary level, "ecological overshoot" (Catton, 1982). The issue is further amplified by the way these pressures interact to magnify their effects: for instance, when trees are cut down faster than they re-grow, nature's ability to sequester carbon dioxide is also reduced, and the rate at which carbon accumulates in the atmosphere increases. Ecological overshoot indicates that ecosystem services (mainly provisioning services) are demanded at a pace faster than they can be renewed, diminishing opportunities for wild species.

As the world population and economy grow, so do pressures on biodiversity. Therefore, some may argue that GDP rather than Footprint could be used as a good proxy for human pressure on ecosystems. However, the sole use of GDP as a proxy for overall pressure on biodiversity would have a number of drawbacks compared to Footprint. First, each dollar has a vastly different demand on biocapacity – paying a poet vs. paying for gasoline may serve as an example. Secondly, GDP does not allow us to understand the upper limit to human demand and, in turn, set benchmarks and thresholds. Conversely, comparing Ecological Footprint and biodiversity at global level provides an indication that the human metabolism has already passed safe planetary boundaries (Rockström et al., 2009). Thirdly, Footprint accounts allow tracing demand from consumer back to origin – making the physical connection apparent. Beside this, comparing Ecological Footprint of production and biocapacity at the national level provides indications on the main hotspots of human pressures on ecosystems and suggests that something has to give[3] if overuse and depletion of ecosystems is to be stopped.

While additional research and investments are needed to link assessments of the human society's use of resources (e.g., through the Ecological Footprint) with a particular biodiversity pressure on a specific ecosystem (GEO BON, 2011), a larger Footprint is highly likely to tighten one or more of the five above-mentioned mechanisms. It is possible, in case studies, to link particular consumption to particular biodiversity threats. For instance, consumption of a specific palm oil product can be tracked to specific plantations, or soy-fed beef can be linked to the particular soy farms that may have replaced primary forests. Understanding the interactions between biodiversity, the drivers of biodiversity loss and humanity's Footprint is fundamental to slowing, halting and reversing the ongoing declines in natural ecosystems and populations of wild species. A short example on Switzerland shift in agricultural practice illustrates the case. But similar case stories could be shown on Kenya's loss of megafauna in the context of the rapid disappearance of Kenya's biocapacity reserve, or the increasing export pressures on Brazil's rapidly shrinking biocapacity reserve.

4.2. Switzerland pressure trends as an example

Over the past few decades, countries in Europe have considerably increased their trade flows (Giljum et al., 2009). While this has allowed income to increase and pressures on European ecosystems to decrease, it has also caused pressure to increase on ecosystems outside the EU borders (EEA, 2012). Weinzettel et al. (2013), for instance, found Europe to be among the top regions displacing land use and placing high pressure on ecosystems in lower-income countries.

A similar path has been experienced by Switzerland as reported in Fig. 6. Pressure on local ecosystems, as measured by the Ecological Footprint of production, has rapidly increased by a factor of 1.7 from 1961 to 1973, and has stabilized ever since (+6% over the period 1974–2008) at a level higher than the local biocapacity. This was due, among other factors, to a reduction in agricultural intensity caused by decreased agricultural subsidies and, in turn, it helped biodiversity in Swiss agricultural lands (particularly pastoral biodiversity) to improve (Darani, 2009; Peter and Lüscher, 2009). However, the overall demand for agricultural and livestock products did not decrease but rather imported products replaced local products in an attempt to keep satisfying Swiss consumption requirements. Net import of biocapacity from outside Swiss borders increased by a factor of 1.5 during the period 1974–2008, mainly because of increased imports of regulating services as well as biocapacity from forest and agricultural ecosystems. As a result, the Footprint of net trade exceeded the Footprint of production activities by 2007, the Ecological Footprint of consumption activities kept increasing (+26% from 1974 to 2008) and the overall pressure on ecosystems did not diminish but rather shifted from national to external ecosystems.

As of 2008, about half of the resource and ecological service demand of Swiss residents was satisfied through net imports. Top five exporters of forest biocapacity to Switzerland were Germany, France, Austria, Sweden and the Russian Federation while agricultural biocapacity was mainly imported from Ukraine, France, USA, China and Mexico (Fig. 7).

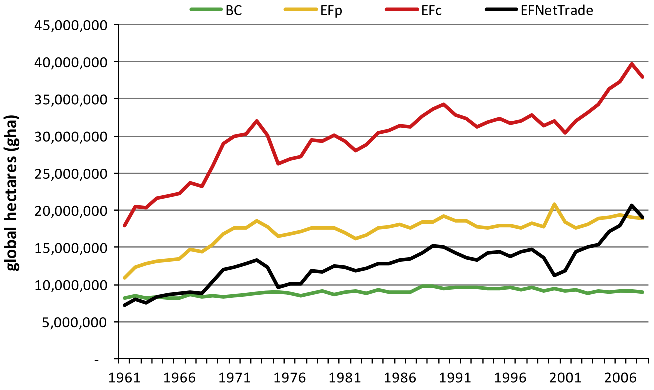

Fig. 6. Switzerland Ecological Footprint of production (EF_p), consumption (EF_c) and net trade, as well as biocapacity (BC), 1961–2008.

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[3] Factors that determine the difference between demand on biocapacity and supply of biocapacity are technological improvements for increasing resource efficiency or decoupling, reduction in consumption or reduction in population size.

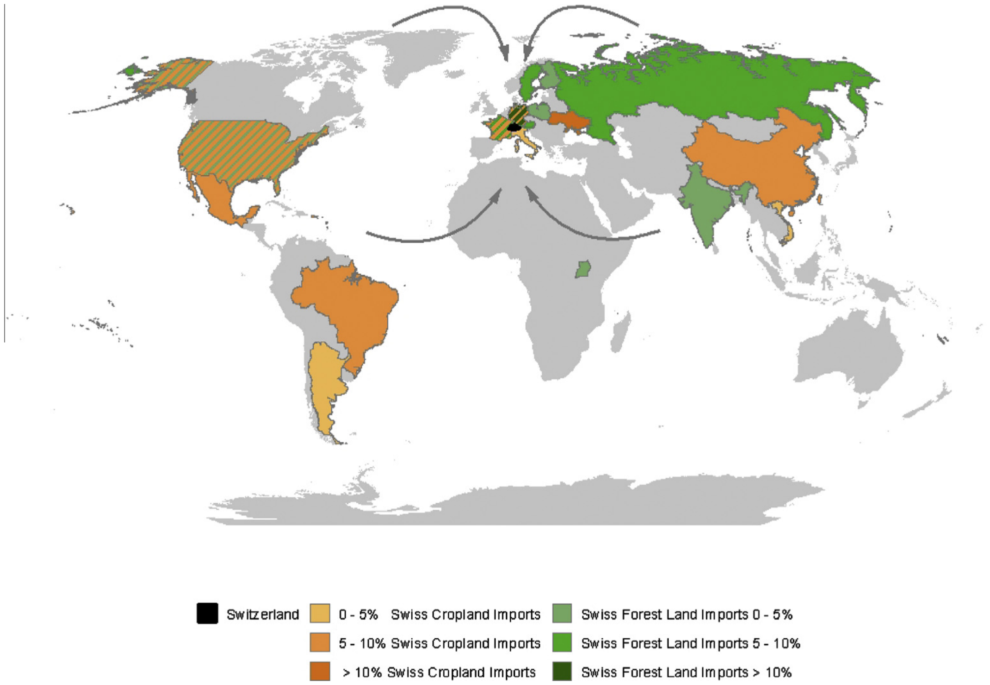

Fig. 7. Top ten exporters of forest (shade of green) and cropland (shade of orange) biocapacity to Switzerland, 2008. Both colors are used (Germany, France and USA) for countries (among the top ten) from which Switzerland is importing both forest and cropland biocapacity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In line with previous studies (e.g., Meyfroidt et al., 2010; Weinzettel et al., 2013), the Ecological Footprint analysis indicates that consumption of agricultural and forest products in Switzerland drives the displacement of human-induced pressure on crop and forest ecosystems in other countries. Gains in the protection of domestic ecosystems were achieved at the expense of an increased pressure on ecosystems outside Switzerland.

5. Conclusion

According the SCBD (2011), "*…it is only possible to reduce or halt the loss of biodiversity if the drivers and pressures on biodiversity are themselves reduced or eliminated. With rising human population and income, the demand for biological resources is increasing, and without action this will translate into increased pressures on biodiversity*".

In an increasingly resource constrained world, accurate and effective accounting systems are needed to map demand and supply for ecosystem services, if we are to provide decision-makers with science-based information necessary to set targets and draft policies. A central goal of Global Footprint Network is thus to bring the reality of resource and ecological services constraints into national and international planning practices by means of advancing Ecological Footprint accounting. We aim to help policy analysts and decision-makers more deeply understand the threats our activities pose on biodiversity and, in turn, the risks that resource limitation and declining biodiversity pose to our societies' social and economic stability.

In October 2010, governments and decision makers gathered in Nagoya, Japan, and decided to adopt renewed biodiversity targets and new indicators for the post-2010 era. However, for this effort to have greater success than its predecessor in tackling the biodiversity crisis, new approaches to implementation are now needed, which will enable preservation of biodiversity while ensuring the well-being of mankind.

Traditional conservation measures (protected areas, biodiversity-related aids, legislation on invasive species, etc.) must be coupled with others that directly target human causes of pressures on biodiversity, and adequately value the benefits (both economic and socio/cultural) that biodiversity has for humans – as identified by the Aichi Biodiversity Target 4. The Ecological Footprint can help track the underlying drivers of biodiversity loss, although it needs to be complemented with other indicators for a comprehensive monitoring of the pressures humans pose on the Biosphere's ecosystems and biodiversity.

As such, the Ecological Footprint was listed among the potential category "A" indicators[4] for use in monitoring Target 4 of the *Strategic Plan for Biodiversity 2011–2020* by both SBSTTA and AHTEG (see UNEP/CBD/COP/11/2). This position was also supported by the CBD Executive Secretary (see UNEP/CBD/COP/10/27/Add.1). Despite this, at the recent COP11 meeting in Hyderabad, Parties to the CBD indicated that it should be left to governments to decide which indicator to use for monitoring Aichi targets and decided not to accept the Ecological Footprint as a global indicator. The Ecological Footprint was therefore moved to the status of category "C" indicator (see UNEP/CBD/COP/11/35).

We hope this paper will contribute to a better understanding of the Ecological Footprint's role in informing biodiversity conservation by providing information on (a) the overall human pressure on the Earth's ecological assets, (b) the ecosystem services under the highest human induced pressure and (c) the main drivers behind such pressure. Our economics and governance systems must begin to recognize this fundamental truth: our well-being depends on the well-being of our natural capital. As long as humanity's metabolism of the earth's resources continues to outstrip the rate at which nature can regenerate the resources, biodiversity – and the entire human enterprise – will come increasingly and ever more perilously under threat.

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[4] The set of (A) and (B) indicators are those which should be used to assess progress at the global level while the (C) indicators are illustrative of some of the additional indicators available to Parties to use at the national level according to their national priorities and circumstances.

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References

Abdullatif, L., Alam, T., 2011. The UAE Ecological Footprint Initiative. <http://awsassets.panda.org/downloads/enfinalreportecologicalfootprint.pdf> (accessed 12.01.13).

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., et al., 2012. Approaching a state shift in Earth's biosphere. Nature 486, 52–58.

Bauler, T., 2012. An analytical framework to discuss the usability of (environmental) indicators for policy. Ecological Indicators 17, 38–45.

Biodiversity Indicators Partnership (BIP), 2010. Biodiversity Indicators and the 2010 Target: Experiences and Lessons Learnt from the 2010 Biodiversity Indicators Partnership. Secretariat of the Convention on Biological Diversity, Montréal, Canada. Technical Series No. 53, 196 pages.

Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., et al., 2013. Accounting for demand and supply of the Biosphere's regenerative capacity: the National Footprint Accounts' underlying methodology and framework. Ecological Indicators 24, 518–533.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., et al., 2010. Global biodiversity: indicators of recent declines. Science 328, 1164–1168.

Butchart, S.H.M., Scharlemann, J.P.W., Evans, M.I., Quader, S., Aricò, S., et al., 2012. Protecting important sites for biodiversity contributes to meeting global conservation targets. PLoS One 7 (3), e32529.

Cassman, K.G., Dobermann, A., Walters, D.T., 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. Ambio 31, 132–140.

Catton Jr, W.R., 1982. Overshoot: The Ecological Basis of Revolutionary Change. The University of Illinois Press, Urbana, IL, USA.

CBD (Convention on Biological Diversity), 2006. Framework for Monitoring Implementation of the Achievement of the 2010 Target and Integration of Targets into the Thematic Programmes of Work, COP 8 Decision VIII/15. <www.cbd.int/decisions> (2006).

CBD (Convention on Biological Diversity), 2010. Decision X/2, The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets. Nagoya, Japan, 18 to 29 October 2010.

Chapin, F.S., Carpenter, S.R., Kofinas, G.P., Folke, C., Abel, N., et al., 2009. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. Trends in Ecology & Evolution 25 (4), 241–249.

Darani, B., 2009. Mehr Magerwiesen im Kanton ZH, Naturschutz.ch. (in German). <http://naturschutz.ch/news/biodiversitaet/mehr-magerwiesen-im-kanton-zh/21224>.

DeFries, R.S., Foley, J.A., Asner, G.P., 2004. Land-use choices: balancing human needs and ecosystem function. Frontiers in Ecology and the Environment 2 (5), 249–257.

DeFries, R.S., Rudel, T., Uriarte, M., Hansen, M., 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nature Geoscience 3, 178–181.

DG Environment, (Directorate General of the Environment, European Commission), 2008. Potential of the Ecological Footprint for Monitoring Environmental Impact from Natural Resources Use – Analysis of the Potential of the Ecological Footprint and Related Assessment Tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources. Report to the European Commission, DG Environment, Final, Report, 2 March 2008.

ECOTEC Research & Consulting Limited, 2001. Ecological Footprinting. Technical Report Commissioned by European Parliament, Directorate General for Research, Directorate A, The STOA Programme to the STOA Panel. Workplan Ref.: EP/IV/A/STOA/2000/09/03. <http://www.europarl.europa.eu/RegData/etudes/etudes/join/2001/297571/DG-4-JOIN_ET%282001%29297571_EN.pdf> (accessed 12.01.13).

EEA (European Environmental Agency), 2010. EU 2010 Biodiversity Baseline. EEA Technical Report No. 12/2010. European Environment Agency, Copenhagen, Denmark. <http://www.eea.europa.eu/publications/eu-2010-biodiversity-baseline>.

EEA (European Environmental Agency), 2012. Environmental Indicator Report 2012: Ecosystem Resilience and Resource Efficiency in a Green Economy in Europe. <http://www.eea.europa.eu/publications/environmental-indicator-report-2012>.

Ellis, E.C., Goldewijk, K.K., Siebert, S., Lightman, D., Ramankutty, N., 2010. Anthropogenic transformation of the biomes, 1700 to 2000. Global Ecology and Biogeography 19, 589–606.

Essl, F., Dullinger, S., Rabitsch, W., Hulme, P.E., Hülber, K., et al., 2011. Socioeconomic legacy yields an invasion debt. PNAS 108, 203–207.

Ewing, B., Reed, A., Galli, A., Kitzes, J., Wackernagel, M., 2010. Calculation Methodology for the National Footprint Accounts, 2010 Edition. Global Footprint Network, Oakland. <http://www.footprintnetwork.org/images/uploads/National_Footprint_Accounts_Method_Paper_2010.pdf>.

FAO, 1998. Global Fiber Supply Model. ftp://ftp.fao.org/docrep/fao/006/X0105E/X0105E.pdf (accessed November 2013).

FAO and IIASA (International Institute for Applied Systems Analysis), 2000. Global Agro-Ecological Zones. http://www.fao.org/ag/agl/agll/gaez/index.htm (accessed November 2012).

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., et al., 2011. Solutions for a cultivated planet. Nature 478, 337–342.

Food and Agriculture Organization of the United Nations-Statistical Databases (FAOSTAT), 2011. http://faostat.fao.org/site/291/default.aspx (accessed February 2011).

Galli, A., Kitzes, J., Wermer, P., Wackernagel, M., Niccolucci, V., Tiezzi, E., 2007. An exploration of the mathematics behind the Ecological Footprint. International Journal of Ecodynamics 2 (4), 250–257.

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., Giljum, S., 2012. Integrating ecological, carbon and water footprint into a "Footprint Family" of indicators: definition and role in tracking human pressure on the planet. Ecological Indicators 16, 100–112.

Galloway, J.N., Aber, J.D., Erisman, J.W., Seitzinger, S.P., Howarth, R.W., Cowling, E.B., Cosby, B.J., 2003. The nitrogen cascade. BioScience 53, 341–356.

GEO BON (Group on Earth Observations – Biodiversity Observation Network), 2011. Adequacy of Existing Biodiversity Observation Systems to support the CBD 2020 Targets. Report in Preparation for the Ad-Hoc Technical Expert Group on Indicators (AHTEG).

Giljum, S., Hinterberger, F., Lutter, S., Polzin, C., 2009. How to Measure Europe's Resource Use. An Analysis for Friends of the Earth Europe. Sustainable Europe Research Institute, Vienna.

Global Footprint Network, 2010. Harmonizing the National Footprint Accounts with the System of Integrated Environmental and Economic Accounting. <http://unstats.un.org/unsd/envaccounting/ceea/meetings/UNCEEA-5-11.pdf.

Global Footprint Network, 2011. National Footprint Accounts, 2011. Available at: <www.footprintnetwork.org>.

Goudie, A., 1981. The Human Impact on the Natural Environment: Past, Present, and Future. Blackwell Publishing, USA.

Gulland, J.A., 1971. The Fish Resources of the Ocean. Fishing News, West Byfleet, Surrey, United Kingdom.

Haberl, H., 2006. The global socioeconomic energetic metabolism as a sustainability problem. Energy 31, 87–99.

Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., Fischer-Kowalski, M., 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences of the United States of America 104, 12942–12947.

Halpern, B.S., Longo, C., Hardy, D., McLeod, K.L., Samhouri, J.F., et al., 2012. An index to assess the health and benefits of the global ocean. Nature 488, 615–620.

Heink, U., Kowarik, I., 2010. What are indicators? On the definition of indicators in ecology and environmental planning. Ecological Indicators 10, 584–593.

Hild, P., Schmitt, B., Decoville, A., Mey, M., Welfring, J., 2010. The Ecological Footprint of Luxembourg – Technical Report (Version 4.2 – Extended Scoping Study Report). CRP Henri Tudor/CRTE, Luxembourg.

IEA Statistics and Balances. http://data.iea.org/ieastore/statslisting.asp (accessed November 2011).

IPCC (Intergovernmental Panel on Climate Change), 2006. IPCC Guidelines for National Greenhouse Gas Inventories, vol. 4: Agriculture Forestry and Other Land Use, http://www.ipccnggip.iges.or.jp/public/2006gl/vol4.html (accessed November 2010).

Khatiwala, S., Primeau, F., Hall, T., 2009. Reconstruction of the history of anthropogenic CO2 concentrations in the ocean. Nature 462, 346–350.

Kitzes, J., Peller, A., Goldfinger, S., Wackernagel, M., 2007. Current methods for calculating national ecological footprint accounts. Science for Environment & Sustainable Society 4 (1), 1–9.

Kitzes, J., Wackernagel, M., Loh, J., Peller, A., Goldfinger, S., et al., 2008. Shrink and share: humanity's present and future ecological footprint. Philosophical Transactions of the Royal Society B 363, 467–475.

Kitzes, J., Galli, A., Bagliani, M., Barrett, J., Dige, G., et al., 2009. A research agenda for improving national ecological footprint accounts. Ecological Economics 68 (7), 1991–2007.

Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., Geschke, A., 2012. International trade drives biodiversity threats in developing nations. Nature 486, 109–112.

Loh, J., Green, R.E., Ricketts, T., Lamoreux, J., Jenkins, M., et al., 2005. The Living Planet Index: using species population time series to track trends in biodiversity. Philosophical Transactions of the Royal Society of London B 360, 289–295.

Maes, J., Paracchini, M.L., Zulian, G., Dunbar, M.B., Alkemade, R., 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. Biological Conservation 155, 1–12.

McCarthy, D.P., Donald, P.F., Scharlemann, J.P.W., Buchanan, G.M., Balmford, A., et al., 2012. Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. Science 338 (6109), 946–949.

McShane, T.O., Hirsch, P.D., Trung, T.C., Songorwa, A.N., Kinzig, A., et al., 2011. Hard choices: making trade-offs between biodiversity conservation and human well-being. Biological Conservation 144, 966–972.

MEA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC (Figure 3, Main Direct Drivers).

Meyfroidt, P., Rudel, T.K., Lambin, E.F., 2010. Forest transitions, trade, and the global displacement of land use. PNAS 107, 20917–20922.

Moldan, B., Janousková, S., Hák, T., 2012. How to understand and measure environmental sustainability: indicators and targets. Ecological Indicators 17, 4–13.

Monfreda, C., Wackernagel, M., Deumling, D., 2004. Establishing national natural capital accounts based on detailed ecological footprint and biocapacity assessments. Land Use Policy 21, 231–246.

Moore, D., Galli, A., Cranston, G.R., Reed, A., 2012. Projecting future human demand on the Earth's regenerative capacity. Ecological Indicators 16, 3–10.

Mora, C., Tittensor, D.P., Adl, S., Simpson, A.G.B., Worm, B., 2011. How many species are there on earth and in the ocean? PLoS Biology 9 (8), e1001127.

Nelson, G.C., Bennett, E., Berhe, A.A., Cassman, K., DeFries, R., et al., 2006. Anthropogenic drivers of ecosystem change: an overview. Ecology and Society 11 (2), 29, <http://www.ecologyandsociety.org/vol11/iss2/art29/>.

Pauly, D., Christensen, V., 1995. Primary production required to sustain global fisheries. Nature 374, 255–257.

Pereira, H.M., Navarro, L.M., Martins, I.S., 2012. Global biodiversity change: the bad, the good, and the unknown. Annual Review of Environment and Resources 37, 25–50.

Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., et al., 2013. Essential biodiversity variables. Science 339, 277–278.

Peter, M., Lüscher, A., 2009. Floristische Entwicklung der Magerwiesen in den Alpen. Agrarforschung 16(3), 76–81 (in German). <http://www.agrarforschungschweiz.ch/archiv_11de.php?id_artikel=1459>.

Phalan, B., Onial, M., Balmford, A., Green, R.E., 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333, 1289–1291.

Pyšek, P., Jarošík, V., Hulme, P.E., Kühn, I., Wild, J., et al., 2010. Disentangling the role of environmental and human pressures on biological invasions across Europe. PNAS 107, 12157–12162.

Rockström, R., Steffen, W., Noone, K., Persson, A., Chapin, F.S., et al., 2009. A safe operating space for humanity. Nature 461, 472–475.

RPA – Risk & Policy Analysts Ltd., 2007. A Review of Recent Developments in, and The Practical Use of, Ecological Footprinting Methodologies: A Report to the Department for Environment, Food and Rural Affairs. Defra, London. <www.footprintnetwork.org/download.php?id=402> (accessed 19.01.13).

Rulli, M.C., Saviori, A., D'Odorico, P., 2013. Global land and water grabbing. Proceedings of the National Academy of Sciences of the United States of America 110 (3), 892–897.

SCBD (Secretariat of the Convention on Biological Diversity), 2003. Handbook of the Convention on Biological Diversity. Earthscan, London.

SCBD (Secretariat of the Convention on Biological Diversity), 2010. Global Biodiversity Outlook 3. CBD, Montréal, Canada, 94 pp.

SCBD (Secretariat of the Convention on Biological Diversity), 2011. COP-10 "Further Information" Document. <http://www.cbd.int/doc/meetings/cop/cop-10/information/cop-10-inf-12-rev1-en.pdf>.

Swartz, W., Sala, E., Tracey, S., Watson, R., Pauly, D., 2010. The spatial expansion and ecological footprint of fisheries (1950 to present). PLoS One 5, e15143.

UNECE and FAO, 2000. Temperate and Boreal Forest Resource Assessment. UNECE, FAO, Geneva.

UN Commodity Trade Statistics Database, 2011. http://comtrade.un.org (accessed November 2013).

UNEP/CBD/COP/10/27/Add.1. Strategic Plan for Biodiversity 2011–2020, Provisional Technical Rationale, Possible Indicators and Suggested Milestones for the Aichi Biodiversity Targets – Note by the Executive Secretary. <http://www.cbd.int/doc/meetings/cop/cop-10/official/cop-10-27-add1-en.pdf> (accessed 08.10.13).

UNEP/CBD/COP/11/2. Recommendations Adopted by the Subsidiary Body on Scientific, Technical and Technological Advice at its Fifteenth Meeting, Montreal, 7–11 November 2011. <http://www.cbd.int/doc/recommendations/sbstta-15/full/sbstta-15-rec-en.pdf> (accessed 08.10.13).

UNEP/CBD/COP/11/35. Decisions Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Eleventh Meeting, Hyderabad, India, 8–19 October 2012. <http://www.cbd.int/doc/decisions/cop-11/full/cop-11-dec-en.pdf> (accessed 08.10.13).

von Stokar, T., Steinemann, M., Rüegge, B., 2006. Ecological Footprint of Switzerland. Technical Report. INFRAS. <http://www.bfs.admin.ch/bfs/portal/de/index/themen/21/03/01.parsys.0003.downloadList.00031.DownloadFile.tmp/ecologicalfootprinttechnicalreport.pdf> (accessed 13.01.13).

Wackernagel, M., Onisto, L., Linares, A.C., Falfán, I.S.L., García, J.M., Guerrero, A.I.S., Guerrero, M.G.S., 1997. Ecological Footprints of Nations: How Much Nature Do They Use? How Much Nature Do They Have? Commissioned by the Earth Council for the Rio+5 Forum. Distributed by the International Council for Local Environmental Initiatives, Toronto.

Wackernagel, M., Schulz, B., Deumling, D., Linares, A.C., Jenkins, M., et al., 2002. Tracking the ecological overshoot of the human economy. Proceedings of the National Academy of Sciences of the United States of America 99 (14), 9266–9271.

Walpole, M., Almond, R.E.A., Besançon, C., Butchart, S.H.M., Campbell-Lendrum, D., et al., 2009. Tracking progress toward the 2010 biodiversity target and beyond. Science 325 (5947), 1503–1504.

Weinzettel, J., Hertwich, E.G., Peters, G.P., Steen-Olsen, S., Galli, A., 2013. Affluence drives the global displacement of land use. Global Environmental Change 23, 433–438.

WWF, Global Footprint Network, Zoological Society of London, 2008. Living Planet Report 2008. WWF, Gland Switzerland.

WWF Japan and Global Footprint Network, 2012. Japan Ecological Footprint Report 2012. WWF Japan, Tokyo. <www.footprintnetwork.org> (accessed 12.01.13).