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Short communication

Answers to common questions in Ecological Footprint accounting

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1. Introduction

The Ecological Footprint measures the amount of biologically productive land and water area required to support the demands of a population or productive activity. Since its creation more than 15 years ago by William Rees and Mathis Wackernagel (Wackernagel, 1991a,b; Rees, 1992; Wackernagel and Rees, 1996), Ecological Footprint accounts have been created for nations (Wackernagel and Rees, 1996; Bicknell et al., 1998; Van Vuuren and Smeets, 2000; Ferng, 2001; Haberl et al., 2001; Lenzen and Murray, 2001; McDonald and Patterson, 2004; von Stokar et al., 2006; WWF, 2006; Moran et al., 2008), cities and regions (Folke et al., 1997; Wackernagel, 1998; Best Foot Forward, 2002; Bagliani et al., 2003; EPA Victoria, 2005; Walsh et al., 2006; Lammers et al., 2008), businesses (Barrett and Scott, 2001; Lenzen et al., 2003), and individuals (Redefining Progress, 2002; EPA Victoria, 2008). Across scales, analysts apply Ecological Footprint accounting methods to understand a population's or activity's demand for the planet's limited capacity to provide a range of ecosystem goods and services.

The basic methodologies behind Ecological Footprint accounting have been widely published in various forms (Wackernagel et al., 1996; Ferng, 2001; Lenzen et al., 2001; Monfreda et al., 2004; WWF, 2006; Galli et al., 2007; Kitzes et al., 2007, 2008), and these publications have engendered specific critiques and commentary (Van Den Bergh and Verbruggen, 1999; Chambers, 2001; George and Dias, 2005; Schaefer et al., 2005). The resulting discontinuous back-and-forth dialogue has created a great deal of confusion among both the general public and practitioners in the field, and few attempts have been made in recent years to systematically lay out the fundamental framework of Ecological Footprint accounting in a public forum.

This article aims to help clarify the discussion surrounding Ecological Footprint accounting methodology by providing brief answers to 16 common questions often asked about Ecological Footprint accounting.

2. Questions and responses

We compiled these questions from technical support queries sent to Global Footprint Network (www.footprintnetwork.org), an international non-governmental organization dedicated to advancing the science and application of the Ecological Footprint, from summer 2005 through spring of 2008.

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Responses are grouped into three categories, covering general accounting methods and principles, the relationship of the Ecological Footprint to specific environmental concerns, and matters of interpretation and application of the Footprint indicator. All replies are based on an Ecological Footprint framework and basic concepts of the original Wackernagel and Rees (1996). Ecological Footprint book, subsequent extensions (Monfreda et al., 2004; Kitzes et al., 2007), and current Ecological Footprint Standards (Global Footprint Network, 2006). Other authors who have employed very different methods (e.g., Lenzen et al., 2007) may propose responses differing from those below.

Interested readers who wish to review more background on Ecological Footprint methodology, or read beyond the brief responses here, are encouraged to begin by consulting Wackernagel and Rees (1996), Ferng (2001), Lenzen and Murray (2001), Monfreda et al. (2004), and Kitzes et al. (2007, forthcoming).

2.1. Methodology

What is the definition of the Ecological Footprint?

The Ecological Footprint is a resource accounting tool that measures how much biologically productive land and sea is used by a given population or activity, and compares this to how much land and sea is available, using prevailing technology and resource management schemes (Rees, 1992; Wackernagel et al., 1996). Productive land and sea areas support human demands for food, fibre, timber, energy, and provides space for infrastructure. These areas also absorb the waste products from the human economy. The Ecological Footprint measures the sum of these areas, wherever they physically occur on the planet. These physical areas are often weighted according to their relative productivity and expressed in global hectares.

What is the specific research question behind Ecological Footprint accounting?

Ecological Footprint accounts answer a specific research question: how much of the regenerative biological capacity of the planet is demanded by a given human activity? Activities here may refer to a population's consumption of resources, the production of a good, or the provision of a service.

To answer this question, the Ecological Footprint measures the amount of biologically productive land and water area an individual, a city, a country, a region, or all of humanity uses to produce the resources it consumes and to absorb the waste it generates under current technology and resource management practices. This demand on the biosphere can be compared to biocapacity, a measure of the amount of biologically productive land and water available for human use. Biologically productive land includes areas such as cropland, forest, and fishing grounds, and excludes deserts, glaciers, and the open ocean.

Studies that are compliant with current Ecological Footprint Standards (Global Footprint Network, 2006) use global hectares (Monfreda et al., 2004) as a measurement unit. Global hectares are hectares with world-average productivity for all productive land and water areas in a given year. The use of a common unit makes Ecological Footprint results globally comparable, similar to financial assessments that use one currency such as dollars or Euros to compare transactions and financial flows throughout the world.

How is an Ecological Footprint calculated?

Ecological Footprints can be calculated for individual people, groups of people (such as a nation), and activities (such as manufacturing a product).

The Ecological Footprint of a person is calculated by considering all of the biological materials consumed, and all of the biological wastes generated, by that person in a given year. These materials and wastes each demand ecologically productive areas, such as cropland to grow potatoes, or forest to sequester fossil carbon dioxide emissions. All of these materials and wastes are then individually translated into a required number of global hectares.

To accomplish this, the amount of material consumed by that person (tonnes per year) is divided by the yield of the specific land or sea area (annual tonnes per hectare) from which it was harvested, or where its waste material was absorbed. The number of hectares that result from this calculation are then converted to global hectares using yield and equivalence factors (Galli et al., 2007). The sum of the global hectares needed to support the resource consumption and waste generation of the person gives that person's total Ecological Footprint.

The Ecological Footprint of a group of people, such as a city or nation, is simply the sum of the Ecological Footprint of all the residents of that city or nation (e.g., EPA Victoria, 2005). It is also possible to construct an Ecological Footprint of Production for a city or nation, which instead sums the Ecological Footprint of all resources extracted and wastes generated within the borders of the city or nation.

The Ecological Footprint of an activity, such as producing a good (an airplane) or service (providing insurance), is calculated in a similar manner by summing the Ecological Footprint of all of the material consumed and waste generated during that activity. When applying Ecological Footprint analysis to a business or organization, analysts must clearly define the individual activities to be included within the boundaries of that organization. The carbon dioxide emitted directly from fuel combustion in an airplane, for example, could be allocated entirely or partially to the airline business, the company that financed the airplane, the company that built the airplane, the businesses or individuals using the airplane, and so forth. Organizational Ecological Footprint studies should clearly document the boundary assumptions associated with each study (Global Footprint Network, 2006).

How does the Ecological Footprint address waste flows?

Waste is associated with all human activities, and hence is an integral part of Ecological Footprint analysis. From an Ecological Footprint perspective, the term 'waste' includes three different categories of materials, and each category is treated differently within Footprint accounts.

First, biological wastes such as residues of crops, animal products, fish products, timber, and carbon dioxide emitted from fuel wood or fossil fuel combustion are all included implicitly within Ecological Footprint accounts since such waste occurs within a closed biological cycle. For example, a cow grazing on one hectare of pasture has a Footprint of one hectare for *both* creating its biological food products and absorbing its biological waste products. This single hectare provides both services, and thus counting the Footprint of the cow twice (once for material production and once for waste absorption) results in double counting the actual area necessary to support the cow. The Footprint associated with the absorption of wastes produced from biological materials that are harvested is thus not counted in addition to the Footprint of the extraction of the biological materials.

Second, waste also refers to the material specifically sent to landfills. If these landfills occupy formerly biologically productive area, then the Footprint of this landfill waste can be calculated as the infrastructure or built-up area used for its long-term storage.

Finally, waste can also refer to toxics and pollutants that cannot in any way be absorbed or broken down by biological processes, such as many types of plastics or chemicals such as PCB's or dioxins. As the Ecological Footprint measures the productive area required to produce a material or absorb a waste, materials such as plastics that are not created by biological processes nor absorbed by biological systems do not themselves have a defined Ecological Footprint. These types of non-regenerative uses of the biosphere that systematically degrade ecosystem health are best tracked in separate non-Footprint accounts (Kitzes et al., forthcoming).

These toxic materials may, however, be assigned a life-cycle Ecological Footprint stemming from the other biological materials associated with their production. For example, although the chemical PCB may not have an Ecological Footprint related to its own extraction from the biosphere or absorption by biological systems, there is clearly an Ecological Footprint associated with the larger life-cycle processes associated with its production. There may be an Ecological Footprint associated with the fossil carbon emissions from the plant where it was created, the physical area of the plant, the paper products used by workers within the plant, and so on. The Ecological Footprint of all of these biological resources and wastes associated with producing the PCB is often referred to confusingly as the Ecological Footprint of the PCB itself.

2.2. *Relationship to specific environmental concerns*

Is the Ecological Footprint the same as the carbon footprint?

Many organizations use the term 'carbon footprint' to refer to the quantities of carbon dioxide emissions associated with an activity, process, or product (BP, 2008; Wiedmann and Minx, 2008). This 'carbon footprint', commonly measured in tonnes of carbon dioxide equivalents, forms one part of a full Ecological Footprint analysis.

Within a full Ecological Footprint calculation, data on carbon dioxide emissions are translated into the area, in global hectares, required to absorb these carbon emissions (Monfreda et al., 2004). This global hectare-based carbon Footprint can then be added to other components of the Ecological Footprint, such as the cropland Footprint and fishing grounds Footprint, to obtain the total Ecological Footprint of a population or activity.

It has been suggested that the carbon Footprint adds value to carbon emissions data in two ways:

- The carbon Footprint puts the magnitude of emissions into a meaningful context, especially for those unfamiliar with climate science who can more readily visualize and understand to area-based units, such as "one planet living" (WWF, 2006), than mass-based units.
- By translating tonnes of carbon dioxide emissions into global hectares, an area-based carbon Footprint can be compared to other demands on productive land. This larger context can reveal spill-over effects, when reducing demand in one area leads to an increase in demand elsewhere. An Ecological Footprint analysis can answer questions such as: Will shifting from fossil fuels to biomass fuels decrease or increase humanity's overall demand on the planet's biological capacity? Would increasing the use of biomass fuels be more or less effective than returning cropland to forest cover to absorb the fossil carbon dioxide we are emitting?

Using an Ecological Footprint analysis to answer questions about tradeoffs between land uses, however, requires a full understanding of the limitations and appropriate use of an aggregate indicator. For a more complete discussion of the appropriate policy applications of the Ecological Footprint, see Jollands et al. (2003), Barrett et al. (2005), and Kitzes et al. (forthcoming).

How does the Ecological Footprint treat water usage?

The Ecological Footprint of a biological resource represents the amount of biologically productive land and water area required to produce that material. Although freshwater is a natural resource cycled through the biosphere, and related to many of the biosphere's critical goods and services, it is not itself a material made by biologically productive area, or a waste absorbed by it. Ecosystems do not create water as a resource in the same manner as timber, fish, or fiber products. Rather, like land area or energy, water is a production factor in creating biological resources for human use.

As a result, the Footprint of a given quantity of water cannot be calculated with yield values in the same manner as a quantity of crop or wood product. When values for a 'water footprint' are reported, these most commonly refer to either a measurement of total volume of water consumed (e.g., Hoekstra and Chapagain, 2007), or to the Ecological Footprint required for a utility to provide a given supply of water (Lenzen et al., 2003).

A water footprint can also be calculated based on the area of catchments or recharge zone needed to supply a given quantity of water (Luck et al., 2001). The area obtained from this calculation, however, cannot be added to other Ecological Footprint land areas, as this would create double counting (a forest, for example, can be used for both timber production and as a water catchment, but adding these two values together would count the amount of available forest twice).

Ecological Footprint accounts do directly reflect the influence of water availability on the biocapacity of ecosystems. Estimates of the amount of biocapacity that is dependent on freshwater supply, or of the lost capacity associated with water use for non-bioproductive purposes, could be calculated, although to our knowledge, no detailed calculation has been completed. As the relationship between freshwater and biological capacity is highly site specific, this analysis would need to be undertaken at a regional or local scale on a case-by-case basis.

How does the Ecological Footprint relate to biodiversity?

The Ecological Footprint is not an indicator of the state of biodiversity, and the biodiversity consequences of a certain activity do not directly affect the Ecological Footprint calculation for that activity. Given the same yields, for example, the Ecological Footprint of "sustainably harvested" timber and uncertified timber is identical. These two practices will have very different consequences for the available future capacity of the forest to produce timber, which would be reflected in future biocapacity assessments but not in current Ecological Footprint accounts.

Although not a direct measure of biodiversity, the Ecological Footprint supports biodiversity assessment and conservation in three important ways. First, the Ecological Footprint can be used as an indicator of the drivers or pressures that cause biodiversity loss. For this reason, the Convention on Biodiversity (CBD) and the Streamlining European Biodiversity Indicators (SEBI) processes have both adopted the Ecological Footprint as a key indicator.

Second, the Ecological Footprint can also be used to translate the consumption of a given quantity of material (such as 1 kg of paper) into the specific local land area from which it was harvested (such as 1 m^2 of forest in Finland). After this initial translation, complementary indicators and assessment tools can be used to measure the impact on biodiversity associated with harvesting from that ecosystem.

Finally, to the extent that humans occupy and demand resources and area that would otherwise be used by other wild species, human consumption as measured by the Ecological Footprint can be in direct competition with consumption needs of wild species.

How does the Ecological Footprint account for pollution and toxic waste?

As waste products that cannot in any way be absorbed or broken down by biological processes, materials commonly classified as 'pollutants' or 'toxics' are incompletely captured in most Ecological Footprint analyses. These materials include persistent organic pollutants, heavy metals mined from the lithosphere and released into the biosphere, and long-lived radioactive materials and wastes, among others. Many of the most important concerns surrounding toxic materials, including as human health impacts and long-term storage or remediation, need to be captured with complementary indicators and accounts.

Many of these pollutants and toxics can cause damage to ecosystems when they are released into the environment, however, and this resultant loss of biocapacity can be measured using Ecological Footprint accounting and allocated to the activity that caused the release of the pollutant. The relationships between pollution and ecosystem damage are very site specific, data intensive, and difficult to calculate in practice. Even if no specific calculation is undertaken, however, any loss of biocapacity associated with the release of pollutants will be reflected in future assessments of the affected area.

2.3. Application

How can so many highly heterogeneous components be combined in any meaningful way in a single composite indicator?

Many prominent aggregate environmental indices, such as Environmentally Weighted Material Consumption (van der Voet et al., 2003), and the Environmental Performance Index (Esty et al., 2008), sum heterogeneous subcomponents using weights that are based on expert opinion. While critical to the construction of these aggregate indicators, these non-empirical weighting values make overall interpretation of the values of these indices, and their changes over time, difficult. The Ecological Footprint, in contrast, assigns empirically based weighting coefficients to individual land types based on data on the relative productivity of these different area types. Current Ecological Footprint analysis most commonly base these "equivalence factors" on maps of agricultural suitability (FAO/IIASA, 2000), although other approaches based on NPP have also been explored.

Aggregate indicators such as the Ecological Footprint provide value above and beyond their parts by condensing substantial amounts of information into summarized statistics. Summed global hectare accounts can be used to show the tradeoffs and substitutions that are often made between different ecosystems and to compare aggregate demand on nature to aggregate supply of biological capacity.

Like any composite indicator, however, the aggregate Ecological Footprint data have their limitations. Aggregate results used in isolation can create an overly simplistic view of complex systems and give the impression that improvements in one area always compensate for deteriorations in others. Full Ecological Footprint accounts can be disaggregated into individual components, such as six major land types or several hundred different product categories.

The Ecological Footprint does not appear to account for technology. If technology will continue to make our consumption more efficient and find substitutes for limiting resources, why should we be concerned about today's state of overshoot?

As an accounting tool, the Ecological Footprint in any given year reflects the prevailing technology of that year in calculating total demand for biological capacity. The accounts document only historical states as they occur. As more renewable electricity generation technology has been introduced, for example, the Ecological Footprint of the average kilowatt hour of electricity has fallen, since less fossil carbon is emitted per unit of energy. As paper manufacturing has become more efficient, generating less waste per unit of paper, the Ecological Footprint of paper has fallen accordingly. The Ecological Footprint thus makes no assumption about technological possibilities, but reflects their actual influence on our current demand on the planet.

A global Ecological Footprint analysis shows, however, that each year since the mid-1980s, humanity has demanded more productive capacity than the biosphere can supply, and that historically, gains in yield and efficiency have not been able to compensate for increasing demand. As a result global overshoot has increased over time. By definition, this overshoot leads to depletion of biological capital and the accumulation of wastes in the biosphere. This state represents a risk to global society today, increasing the potential for price shocks, disruption of global supply chains, economic recession, and political turmoil.

The Ecological Footprint seems to ignore factors such as human health and the well-being of society: Aren't these important to sustainability?

The Ecological Footprint measures only human demand for biological goods and services, and does not attempt to capture other aspects of social or economic sustainability. Combining all aspects of sustainability into a single metric can be appealing, but such indicators are difficult to interpret and use as they hide the existence or impossibility of key trade-offs. The Ecological Footprint answers only the question of how much of the planet's productive capacity is demanded. Sustainability means living well, within the means of nature, and the Ecological Footprint highlights a minimum condition for achieving this goal.

The Ecological Footprint is often used in tandem with other indicators describing development or quality of life, such as the UN's Human Development Index (WWF, 2006; Moran et al., 2008). Additionally, comparative Footprint analysis can highlight disparities in consumption of biological resources between different populations, such as high- and low-income nations.

Does the Ecological Footprint determine what is a "fair" or "equitable" use of resources?

The Ecological Footprint is a science-based ecological accounting tool that reports the current state of demand for productive area, along with who demands it, and the amount of productive area available. Footprint accounts quantitatively describe the demand of any individual or a population, but they do not themselves draw conclusions or make assumptions about who should be using what. These are social and political choices that the Ecological Footprint itself cannot make (Kitzes et al., 2008). While the Ecological Footprint can help to inform these choices, what represents a "fair share" or an "equitable use" are moral and ethical questions, and the Ecological Footprint accounts are descriptive in nature.

3. Conclusion

In a rapidly growing field, such as the field of Ecological Footprint analysis, it is inevitable that much confusion about basic definitions and principles will arise. With increasing clarity, future research will proceed more quickly towards deriving robust and useful resource accounts in support of decision making.

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