# Introduction to the Ecological Footprint:
## *Underlying Research Question and Current Calculation Strategy*

Entry prepared for the *Internet Encyclopaedia of Ecological Economics*

Mathis Wackernagel, Ph.D.,* Paul Wermer, Ph.D., Steven Goldfinger, Ph.D.

*Global Footprint Network*
1050 Warfield Avenue
Oakland, CA, 94610 USA
tel.: +1-510-839-8879
fax: +1-510-251-2410
*mathis@footprintnetwork.org
www.footprintnetwork.org

March 12, 2007

### *The Research Question*

There is a big confusion about sustainability. Yet, most would agree that as a necessary (but not sufficient) condition for sustainability, biological resources may not be consumed faster than they can be regenerated. The challenge is how to test this condition.

The Ecological Footprint[i] addresses this one particular research question: *how much of the regenerative capacity of the biosphere is being occupied by human activities?* It does this by measuring how much biologically productive land and water area an individual, a city, a country, a region, or humanity uses to produce the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management schemes. This land and water area can be located anywhere in the world.

Expressing use of biological natural capital in terms of area is useful, since life happens on surfaces, and primary producers – with help of photosynthesis – serve as the solar collectors for powering all animal species. Hence, surface areas matter, and most resource and waste flows can be measured in terms of the biologically productive area necessary to maintain these flows. (Those resource and waste flows that cannot be measured are excluded from the assessment. As a consequence, this assessment tends to underestimate the full Ecological Footprint).

Footprints can be analyzed from a consumption perspective[ii], or at any stage of the production process. They can also be applied at all scales, from global down to any activity of organizations and populations, or for urban development projects, services, and products.

The Ecological Footprint uses a common, standardized measurement unit to make results comparable, similar to financial assessments that use one currency such as dollars or Euros to compare economics. The measurement units for Footprint accounts are global hectares. More precisely, a global hectare is 1 hectare of biologically productive space with world average productivity of the given year. When weighting each area in proportion to its usable resource productivity (that is, its annual production of usable resources and services), the different areas can be converted from hectares and expressed in a (different) number of global hectares of average productivity. "Usable" refers to the portion of biomass used by humans, reflecting the anthropocentric assumptions of the Ecological Footprint measurement.

***Key Results***

In 2003 (the most recent year for which consistent data are available),[iii] the biosphere had 11.2 billion hectares of biologically productive area corresponding to roughly one quarter of the planet's surface. These 11.2 billion hectares include 9 billion hectares of land. The remaining area are water surfaces (ocean shelves and inland water). The land area is composed of 1.5 billion hectares of cropland, 3.5 billion hectares of grazing land, 3.9 billion hectares of forest land, and 0.2 billion hectares of built-up land.

Since these areas stand for mutually exclusive uses, and each global hectare represents the same amount of biomass production potential for a given year, they can be added up. This is the case for both the aggregate human demand (the Ecological Footprint) and the aggregate supply of biocapacity.

The Ecological Footprint calculated for each country includes the resources contained within the goods and services that are consumed by people living in that country, as well as the associated waste. Resources consumed for the production of goods and services that are exported to another country are added to the Footprint of the country where the goods and services are actually consumed, rather than of the country where they are produced.

The global Ecological Footprint is the area of productive biosphere required to maintain the material throughput of the human economy, undercurrent management and production practices. Typically expressed in global hectares, the Ecological Footprint can also be measured in number of planets, whereby one planet represents the biological capacity of the Earth in a given year. Results could also be expressed, for example, in Austrian or Danish hectares, just as financial accounts can use different currencies.

The national analysis is based primarily on data published by the Food and Agriculture Organization of the United Nations (FAO), the International Energy Agency (IEA), UN Statistics Division (UN Commodity Trade Statistics Database - UN Comtrade), and the Intergovernmental Panel on Climate Change (IPCC). Other data sources include studies in peer-reviewed science journals or thematic collections.

These national accounts are now being maintained by the Global Footprint Network,[iv] in partnership with its partners. The purpose of this Network is to build global Footprint accounting standards with an 'open source' approach, so results become comparable and consistent across geography and time.[v]

*Biocapacity and bioproductivity*

Biocapacity (biological capacity) is the total usable biological production capacity in a given year of a biologically productive area, for example within a country. It can be expressed in global hectares. Biologically productive area is land and sea area with significant photosynthetic activity and production of biomass. Marginal areas with patchy vegetation and non-productive areas are not included. There are 11.2 billion global hectares of biologically productive land and sea area on the planet. The remaining three-quarters of the Earth's surface, including deserts, ice caps, and deep oceans, support comparatively low levels of bioproductivity, too dispersed to be harvested. Bioproductivity (biological productivity) is equal to the biological production per hectare per year. Biological productivity is typically measured in terms of annual biomass accumulation. Biocapacity available per person is calculated by dividing the 11.2 billion global hectares of biologically productive area by the number of people alive – 6.3 billion in 2003 – gives the average amount of biocapacity that exists on the planet per person: 1.8 global hectares.

For consistency and to keep the global hectares additive, each area is only counted once as both Ecological Footprint and biocapacity, even if an area provides two or more ecological services at the same time. This is like any farm would be measured – how many hectares it contains, and how many hectares are used (by which crops or forests).

Further the Ecological Footprint calculations avoid double counting along production chains– that is, counting the same area twice. Consider bread: wheat is farmed, milled, and baked, then finally eaten as bread. Economic data can track these sequential processes and report the amounts and financial values at each stage. However, it is the same wheat grain throughout the production process, finally ending up as human consumption. To avoid double counting, the wheat is counted at only one stage of the process, while energy consumed at each stage of the process is added to the Footprint.

Finally, the national Footprint accounts include the productivity of cropland at the level of current yields, with no deduction for possible degradation; however, if degradation takes place it will show up as reductions in future biocapacity assessments. The energy use for agriculture, including fertilizers, is included in the energy Footprint.

### *The carbon Footprint*

The carbon Footprint from burning fossil fuel makes up about half of the global Footprint. Since fossil fuel is not renewed at the rate of consumption, various methods are possible to capture how much of the biosphere's regenerative capacity is occupied by this activity. Building on the UN Framework Convention on Climate Change which aims at stabilizing the $CO_2$ concentration in the atmosphere, the rationale is the following: Burning fossil fuel adds $CO_2$ to the atmosphere. The Footprint of fossil fuel is calculated by estimating the biologically productive area needed to sequester enough $CO_2$ to avoid an increase in atmospheric $CO_2$ concentration.

Since the world's oceans absorb about 1.8 Giga tonnes of carbon every year (IPCC 2001), only the remaining carbon emission is accounted for in the Ecological Footprint. The current capacity of world average forests to sequester carbon is based on FAO's Global Fibre Supply Model (FAO 2000) and corrected where better data are available from other FAO sources such as FAO/UNECE 2000, FAO 1997b, and FAO 2004. Sequestration capacity changes with both the maturity and composition of forests, and with shifts in bioproductivity due to higher atmospheric $CO_2$ levels and associated changes in temperature and water availability.[vi]

Other possible methods to account for fossil fuel use would result in even larger Footprints (Wackernagel and Monfreda 2004; Dukes 2003).

### *What Footprint accounts do NOT include*

The results presented tend to underestimate human demand on nature and overestimate the available biocapacity by:

- choosing the more optimistic bioproductivity estimates when in doubt (e.g. carbon absorption);
- excluding human activities for which there are insufficient data to assess the effect on biocapacity (e.g. acid rain);

- excluding those activities that systematically erode nature's capacity to regenerate. They consist of:
    - uses of materials for which the biosphere has no apparent significant assimilation capacity (e.g. plutonium, polychlorinated biphenyls (PCBs), dioxins, chlorofluorocarbons (CFCs));[vii]
    - processes that irreversibly damage the biosphere (e.g. species extinction, fossil-aquifer depletion, soil erosion, deforestation, desertification).

***Applications***

There have been Footprint applications on every continent. According to Google, there are about one million web pages discussing the Footprint. Global and national accounts have been reported in headlines worldwide, and over 100 cities or regions have assessed their Ecological Footprint, ranging from student projects to comprehensive analyses of a metropolitan area's demand on nature.

*Examples of Municipal Applications*

***London***, for instance, has already gone through three rounds. In 1995, urban sustainability expert Herbert Girardet estimated that the UK capital's Footprint was 125 times the size of the city itself. In other words, in order to function London required an area the size of the entire productive land surface of the UK to provide all the resources the city uses and to dispose of its pollutants and waste.

In 2000, under the leadership of Mayor Ken Livingstone, London commissioned a more detailed Ecological Footprint study called *City Limits*. The report, sponsored by organizations including the Chartered Institution of Wastes Management, the Institution of Civil Engineers (ICE), and the Biffaward Programme on Sustainable Resource Use, was produced by Best Foot Forward and launched in September 2002. Results for this city and its 7 million inhabitants are available at: http://www.citylimitslondon.com.

To respond to the challenges identified by the *City Limits* report, London Remade, a business membership organization supported by over 300 of the capital's major businesses and higher education institutions, wanted to analyze possible steps for reducing London's Footprint. In collaboration with London First, a waste management partnership, it commissioned consulting companies WSP Environmental and Natural Strategies to identify the reduction potential in a project called *Toward Sustainable London: Reducing the Capital's Ecological Footprint*. The first two of four reports, *Determining London's Ecological Footprint and Priority Impact Areas for Action*, are available at: http://www.londonremade.com

Others have studied aspects of city living using the Ecological Footprint. For instance, the Sustainable Consumption Group of the Stockholm Environment Institute at York has led a number of studies of cities and regions (http://www.regionalsustainability.org/). They also contributed, with BioRegional, to a WWF-UK report called *One Planet Living in the Thames Gateway* which identifies Footprint saving potentials for greener urban developments. The report is available at: http://www.wwf.org.uk/filelibrary/pdf/thamesgateway.pdf.

Bill Dunster, UK's leading ecological architect, uses the Footprint as the context for his designs. More on his work can be found at http://www.zedfactory.com.

*Examples of National & Regional Applications*

A number of national and regional Footprint studies have contributed to policy discussions, some in close cooperation with government agencies. For example:

***Wales (pop. 2,900,000).*** The National Assembly for Wales adopted the Ecological Footprint as their headline indicator for sustainability in March of 2001, making Wales the first nation to do so. The first report was commissioned through WWF-Cymru and executed by Best Foot Forward. This report details Welsh energy, transportation and materials management. It can be found at: http://www.wwf-uk.org/filelibrary/pdf/walesfootprint.pdf. An update of the report was produced by Stockholm Environment Institute and is available at http://www.walesfootprint.org.[viii]

***The State of Victoria, Australia (pop. 4,650,000)***. EPA Victoria, the lead state agency responsible for protecting the environment, established a series of pilot projects in 2002 in partnership with a wide range of organizations and businesses to further investigate the practical applications of the Ecological Footprint to promote sustainability. See http://www.epa.vic.gov.au/eco-footprint.

***Sonoma County, California (30 miles north of San Francisco, pop. 495,000).*** Under a grant from the U.S. EPA, Sustainable Sonoma County, a local NGO, used the Ecological Footprint as the foundation of a 2002 campaign. By inviting wide public participation and comment on the study before it was released, it was able to generate strong local buy-in. As a result, the launch of the study got county-wide media coverage and built the groundwork for a subsequent campaign. The latter resulted in all municipalities of Sonoma County committing simultaneously to reduce their $CO_2$ emissions by 20 percent, making it the first U.S. county to do so. To meet this commitment, they established programs that track progress towards meeting their reduction goal. The Sonoma Footprint study is available at: http://www.sustainablesonoma.org/projects/scefootprint.html

***Six Southern regions of Italy.*** Commissioned by WWF Italy, CRAS produced a study comparing the 6 southern regions of Italy. The study is available at: http://www.cras-srl.it/pubblicazioni/32.pdf

***Swiss Footprint Review.*** In late 2006, the Swiss government released the study: "Switzerland's Ecological Footprint: A contribution to the sustainability debate." It was commissioned by the Federal Office for Spatial Development (ARE), the Agency for Development and Cooperation (SDC), the Federal Office for the Environment (FOEN), and the Federal Statistical Office (FSO). The study tested to what extent the international data sources used by "Global Footprint Network" correspond to the statistics of the Swiss Federal Statistical Office. They concluded that the data sets are largely consistent. Also note that, partly as a result from the collaboration, the method used to calculate embodied energy in trade has been revised. For this reason, Switzerland's Ecological Footprint according to the latest edition of Ecological Footprint calculations is larger than the one presented in the Swiss study (which is based on the 2005 Footprint edition). The report is available (as PDF) in a number of languages. For English, visit: http://www.bfs.admin.ch/bfs/portal/en/index/themen/nachhaltige_entwicklung/uebersicht.html

*Examples of International Applications*

***The European Environment Agency (EEA***). EEA sponsored the 2005 Edition of the National Footprint Accounts. http://org.eea.europa.eu/news/Ann1132753060). DG Environment commissioned a research review on how to apply the Ecological Footprint, with results expected by late 2007.

***The European Parliament*** commissioned a comparative study on the application of Ecological Footprinting to sustainability. This study included case studies exploring potential uses of the Footprint in international legislation. The study, completed in 2001, was supervised by the Directorate General for Research, Division Industry, Research, Energy, Environment, and Scientific and Technological Options Assessment (STOA). It is available at http://www.europarl.eu.int/stoa/publi/pdf/00-09-03_en.pdf or as 10-page summaries in 11 European languages at http://www.europarl.eu.int/stoa/publi/default_en.htm.

***The United Nations Population Fund (UNFPA)*** report *State of World Population 2001 - Footprints and Milestones: Population and Environmental Change* builds on Ecological Footprint concepts. See http://www.unfpa.org/swp/2001/english/ch03.html#5

# ENDNOTES

[i] The Ecological Footprint concept builds on a number of earlier work, including Börgstrom (ghost acres) and human appropriation of net primary productivity (Vitousek et al., 1986 [Vitousek, P. M., Ehrlich, P. R., Ehrlich, A. H., Matson, P. A., 1986. Human Appropriation of the Products of Photosynthesis. *BioScience* 36(6), 363-373.]). Initial publications include: William E Rees and M. Wackernagel, "Ecological Footprints and Appropriated Carrying Capacity: Measuring the Natural Capital Requirements of the Human Economy." Chapter 20 in AnnMari Jansson, Carl Folke, Monica Hammer, and Robert Costanza (ed.), 1994. *Investing in Natural Capital*. Island Press Washington DC. Mathis Wackernagel, M. and William E. Rees, *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island. 1996.

[ii] Globally, the consumption Footprint equals the production Footprint. At the national scale, trade must be accounted for, so the consumption Footprint = production Footprint + imports – exports (assuming no significant change in stocks).

[iii] National accounts methodology build on Monfreda et al. (2004) – an updated version of which can be downloaded from www.footprintnetwork.org/gfn_sub.php?content=download. On this site, free academic licenses are available too, containing all the calculations. The Footprint is computed for all countries that are represented in UN statistical data, back to 1961, with approximately 5000 data points and 10 000 calculations per year and country. More than 200 resource categories are included, among them cereals, timber, fishmeal, and fibres. These resource uses are translated into global hectares by dividing the total amount consumed in each category by its global average productivity, or yield. Biomass yields, measured in dry weight, are taken from FAO statistics. Earlier methods were discussed in a special issue of Ecological Economics (2000). [Costanza, R., Ayres, R., Deutsch, L., Jansson, A., Troell, M., Rönnbäck, P., Folke, C., Kautsky, N., Herendeen, R., Moffat, I., Opschoor, H., Rapport, D., Rees, W., Simmons, C., Lewis, K., Barrett. J., Templet, P., Van Kooten, C., Bulte, E., Wackernagel, M. and Silverstein, J. 2000. Commentary Forum: The Ecological Footprint. *Ecological Economics*. Vol. 32 No 3 (2000), p341-394.]

[iv] Global Footprint Network, established as a non-for-profit organization in 2003, seeks to make the planet's ecological limits central to decision making by governments, businesses and households. It does this with its over 75 partner organizations from around the world by increasing the effectiveness and reach of the Ecological Footprint. Standardization of the accounting method is at the core of its strategy, with first standards released in June 2006. More on the science behind the Ecological Footprint and examples of how it has been used to advance sustainability can be found at www.footprintnetwork.org.

[v] More about the initial standards and the standardization process is posted at www.footprintstandards.org.

[vi] IPPC – Intergovernmental Panel on Climate Change. 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK. ; FAO – Food and Agriculture Organization of the United Nations. 1995. World Livestock Production Systems: Current Status, Issues and Trends. FAO, Rome, Italy. FAO – Food and Agriculture Organization of the United Nations. 1997a. State of the World's Fisheries and Aquaculture (SOFIA) 1996. FAO Fisheries Department, Rome, Italy. www.fao.org/docrep/w9900e/w9900e00.htm. FAO – Food and Agriculture Organization of the United Nations. 1997b. State of the World's Forests 1997. FAO, Rome, Italy. www.fao.org/forestry/foris/webview/forestry2/index.jsp?siteId=3321&sitetreeId=10107&langId=1&geoId=. FAO – Food and Agriculture Organization of the United Nations. 2000. Global Fibre Supply Model. FAO, Rome, Italy. www.fao.org/ forestry/fop/fopw/ GFSM/gfsmint-e.stm. FAO – Food and Agriculture Organization of the United Nations. 2001. Forest Resources Assessment 2000. Main Report. FAO Forestry Paper 140. FAO, Rome, Italy. FAO – Food and Agriculture Organization of the United Nations. 2002. FISHSTAT Plus. FAO Fisheries Department, Rome, Italy. www.fao.org/fi/statist/FISOFT/FISHPLUS.asp . FAO – Food and Agriculture Organization of the United Nations. 2003. State of the World's Forests 2003. FAO, Rome, Italy. www.fao.org/DOCREP/005/Y7581E/Y7581E00.HTM . FAO – Food and Agriculture Organization of the United Nations. 2004a. AQUASTAT. FAO's Information System on Water and Agriculture. www.fao.org/ag/agl/aglw/aquastat/main/index.stm . FAO – Food and Agriculture Organization of the United Nations. 2004b. FAOSTAT (FAO statistical databases). FAO, Rome, Italy. http://apps.fao.org. FAO/IIASA – Food and Agriculture Organization of the United Nations and International Institute for Applied Systems Analysis. 2000. Global Agro-Ecological Zones (GAEZ) CD-ROM. www.fao.org/ag/agl/agll/gaez/index.htm. FAO/UNECE – Food and Agriculture Organization of the United Nations and United Nations Economic Commission for Europe. 2000. Temperate and Boreal Forest Resource Assessment 2000. UNECE/FAO, Geneva, Switzerland.

[vii] Michael Braungart suggests the following rule as a test for acceptable human made compounds or molecules: they must not appear in mother milk (otherwise there is bioaccumulation).

[viii] Barrett, J., Birch, R., Cherrett, N., Wiedmann, T., 2005. Reducing Wales' Ecological Footprint – Main Report. Stockholm Environment Institute, University of York; published by WWF Cymru, Cardiff, UK; March 2005. http://www.walesfootprint.org. See also: National Assembly for Wales, 2004. Sustainable Development Indicators for Wales 2004. National Assembly for Wales, Statistical Bulletin 18/2004; http://www.wales.gov.uk/keypubstatisticsforwalesheadline/content/sustainable/2004/hdw20040323-e.htm.