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Current Methods for Calculating National Ecological Footprint Accounts

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The Ecological Footprint is a resource accounting tool that measures how much bioproductive land and sea is available on Earth, and how much of this area is appropriated for human use. The Ecological Footprint, human demand, and biocapacity, ecosystem supply, are both measured in units of global hectares, a hectare normalized to the average productivity of all bioproductive hectares on Earth. As of 2003, there are approximately 11.2 billion global hectares of area available. In that same year, humanity demanded products and services from the equivalent of 14.1 billion global hectares. This overshoot, if it continues, will put global ecosystems at serious risk of degradation or collapse. Humanity's Ecological Footprint is spread across six land use categories: cropland, grazing land, fishing grounds, forest, built-up area, and land for carbon absorption. Of these six, land for carbon absorption is the most significant globally, representing nearly one half of humanity's total Footprint. A concerted international effort to shrink human demand to within the limits set by nature will be an important component of any effort to create a sustainable future for all people.

Keywords: Ecological Footprint, biocapacity, overshoot, resource accounts, sustainability, land use, carbon Footprint

Introduction: The Ecological Footprint

The **Ecological Footprint** is a well known resource accounting tool that measures 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 (Wackernagel and Rees 1996). The Ecological Footprint is most commonly expressed in units of **global hectares.** A global hectare is a hectare that is normalized to have the world average productivity of all biologically productive land and water in a given year. Because of international trade and the dispersion of wastes, hectares demanded can be physically located anywhere in the world.

Many Ecological Footprint reports and applications, including the Living Planet Report 2006 (WWF 2006), report the Ecological Footprint of nations expressed in global hectares per capita. National-level Ecological Footprint calculations can be found from multiple sources, with Global Footprint Network's National Footprint Accounts serving as a common standard. These accounts are maintained and updated by Global Footprint Network with the support of its more than 70 partner organizations. A national Ecological Footprint measures the biological capacity needed to produce the goods and services consumed by residents of that country, as well as the capacity needed to assimilate the waste they generate. Resources used for the production of goods and services that are exported are counted in the

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Ecological Footprint of the country where the goods and services are ultimately consumed.

National Footprint Accounts calculations are based primarily on international data sets published by the Food and Agriculture Organization of the United Nations (FAO), the International Energy Agency (IEA), the 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 and thematic collections.

Biocapacity: Nature's Supply

Biocapacity (or biological capacity) is the capacity of ecosystems to produce useful biological materials and to absorb waste materials generated by humans using current management schemes and extraction technologies. "Useful biological materials" are defined for each year as those used by the human economy that year. What is considered "useful"can change over time (e.g. the use of corn stover to produce cellulosic ethanol would result in corn stover becoming a useful material, thereby increasing the biocapacity of maize cropland). Like the Ecological Footprint, biocapacity is usually expressed in units of global hectares, and is calculated for all biologically productive land and sea area on the planet.

Biologically productive area is land and water (both marine and inland) area that supports significant photosynthetic activity and biomass accumulation that can be used by humans. Non-productive and marginal areas such as arid regions, open oceans, the cryosphere, and other low-productive surfaces are not included. Areas producing biomass that is not of use to humans are also not included. In 2003, the Earth's biosphere had approximately 11.2 billion hectares of biologically productive area, corresponding to roughly one quarter of the planet's surface. These 11.2 billion hectares include 2.4 billion hectares of water (ocean shelves and inland water) and 8.8 billion hectares of land. The land area is composed of 1.5 billion hectares of cropland, 3.4 billion hectares of grazing land, 3.7 billion hectares of forest land, and 0.2 billion hectares of built-up land.

The amount of biocapacity available per person globally is calculated by dividing the 11.2 billion global hectares of biologically productive area by the number of people on Earth (6.3 billion in 2003). This ratio gives the average amount of biocapacity available on the planet per person - 1.8 global

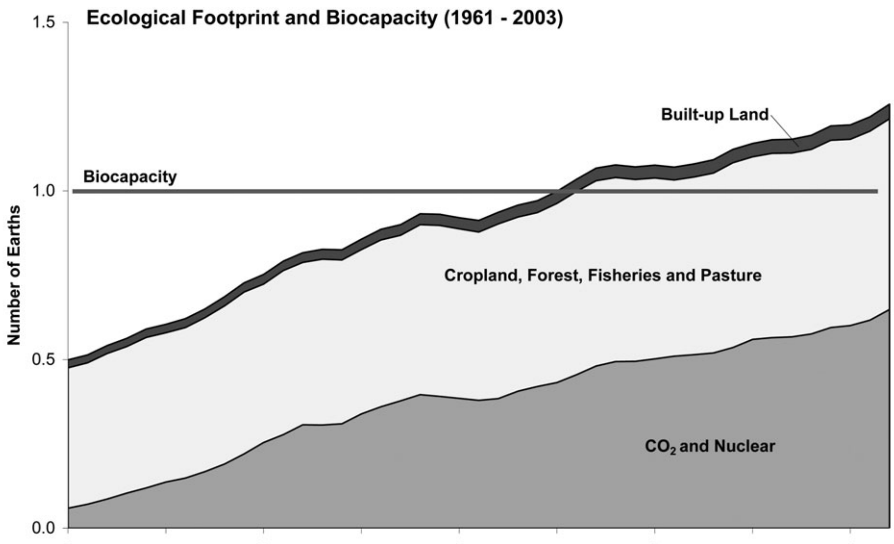

Figure 1: World Overshoot. Humanity's Ecological Footprint, expressed in number of planets demanded, has increased dramatically over the past 40 years. In 2003, humanity demanded the resources and services of at least 1.25 planets.

	Ecological Footprint	Biocapacity
Cropland	3,040,000	3,305,000
Grazing Area	914,000	1,683,000
Fishing Grounds	936,000	859,000
Forest	1,438,000	4,898,000
Carbon	7,263,000	
Built-up Area	483,000	483,000
Total	14,073,000	11,198,000

Table 1: World Ecological Footprint and Biocapacity, 2003. Both Ecological Footprint and biocapacity are expressed here in global hectares. Numbers may not sum due to rounding.

hectares. This simple calculation of available biocapacity assumes that no capacity is set aside for the demands of wild species.

The process of measuring both the Ecological Footprint and biocapacity of a business, city, nation, region, or the planet is often referred to as **Ecological Footprint accounting.** In 2003, global Ecological Footprint accounts showed that humanity's total Footprint exceeded the Earth's biocapacity by approximately 25 per cent. This situation, where Ecological Footprint exceeds available biocapacity,is known as **overshoot.**

Fundamental Assumptions of Ecological Footprint Accounting

Ecological Footprint accounting is based on six fundamental assumptions (Wackernagel et al. 2002):

- The majority of the resources people consume and the wastes they generate can be tracked.
- Most of these resource and waste flows can be measured in terms of the biologically productive area necessary to maintain flows. Resource and waste flows that cannot be measured are excluded from the assessment, leading to a systematic underestimate of humanity's true Ecological Footprint.
- By weighting each area in proportion to its bioproductivity, different types of areas can be converted into the common unit of global hectares, hectares with world average bioproductivity.
- Because a single global hectare represents a single use, and all global hectares in any single year represent the same amount of bioproductivity, they can be added up to obtain an aggregate indicator of Ecological Footprint or biocapacity.
- Human demand, expressed as the Ecological Footprint, can be directly compared to nature's supply, biocapacity, when both are expressed in global hectares.
- Area demanded can exceed area supplied if demand on an ecosystem exceeds that ecosystems regenerative capacity (e.g., humans can temporarily demand more biocapacity from forests, or fisheries, than those ecosystems have available). This situation, where Ecological Footprint exceeds available biocapacity, is known as **overshoot.**

Activities Currently Excluded from Ecological Footprint Accounting

Although the goal of Ecological Footprint accounting is to measure human demand on the biosphere as accurately as possible, the methodology is designed to underestimate human demand on the biosphere where uncertainty exists. Because the Footprint is a historical account, many activities that systematically erode nature's future regenerative capacity are not included in current and past Ecological Footprint accounts. These activities include the release of materials for which the biosphere has no significant assimilation capacity (e.g. plutonium, PCBs, dioxins, and other persistent pollutants) and processes that damage the biosphere's future capacity (e.g., loss of biodiversity, salination resulting from cropland irrigation, soil erosion from tilling). Although the consequences of these activities will be reflected in future Ecological Footprint accounts as a decrease in biocapacity, Ecological Footprint accounting does not currently include risk assessment models that could allow a present accounting of these future damages.

Similarly, Ecological Footprint accounts do not directly account for freshwater use and availability, since freshwater acts as a limit on the amount of biological capacity in an area but is not itself a biologically produced good or service. Although the loss of biocapacity associated with water appropriation or water quality degradation is reflected as a decrease in overall biocapacity in that year, an Ecological Footprint of its use is not currently allocated to the consumer of the water resource.

Tourism activities are currently attributed to the country in which they occur rather than to the traveller's country of origin. This distorts the relative size of some countries' Footprints, overestimating those that host tourists and underestimating the home countries of travellers. Current data constraints also prevent the Footprint associated with the generation of internationally-traded electricity from being allocated to the final consumer of this energy. These two limitations affect the allocation of Ecological Footprint between nations but not the total global Footprint.

The demand on biocapacity resulting from emission of greenhouse gases other than carbon dioxide is not currently included in Ecological Footprint accounts. Incomplete scientific knowledge about the fate of greenhouse gases other than carbon dioxide makes it difficult to estimate the biocapacity required to neutralize their climate change potential.

Ecological Footprint Accounting Methodology

The methodology behind Ecological Footprint accounting continues to undergo significant development and regularly incorporates new data and scientific knowlege as it become available. Global Footprint Network has taken the lead in stewarding this process through the improvement of the National Footprint Accounts and the ongoing Footprint Standards process. The methodology behind the 2006 Edition of the National Footprint Accounts builds on the method described in Monfreda et al. (2004).

Many Ecological Footprint studies report the Footprint of Consumption for nations and the world. Although globally, the Footprint of all goods and services produced must equal the Footprint of all goods and services consumed (minus changes in stocks), this does not hold true at the national level. A nation's Footprint of Consumption equals that nation's Footprint of Primary Production plus imports plus stock changes minus exports. This calculation represents the apparent consumption of biological capacity within a nation.

The National Footprint Accounts calculate a national Footprint of Consumption for all countries that are represented in United Nations statistical data that have populations greater than one million people. Results are available for over 150 nations from 1961 through 2003.

More than 200 resource categories are included in the National Footprint Accounts, including crop products, fibres, livestock, wild and farmed fish, timber, and fuelwood. The accounts also explicitly track one major waste product - carbon dioxide. Demand for resource production and waste assimilation are translated into global hectares by dividing the total amount of a resource consumed (or waste generated) by the global average yield of the land type that produces that resource (or absorbs that waste). This area is multiplied by the appropriate equivalence factor to express the total demand in global hectares for each resource consumed. Yields are calculated based on various international statistics, primarily those from the United Nations Food and Agriculture Organization. The biologically productive area occupied by built-up infrastructure is also included in Footprint accounts, as explained below.

Manufactured or derivative products (e.g., flour or wood pulp), are converted into primary product equivalents (e.g., wheat or roundwood) for the purposes of Ecological Footprint calculations. The quantities of primary product equivalents are then translated into global hectares.

Major Land Use Types in Ecological Footprint Accounting

Ecological Footprint accounting tracks five biocapacity components and six Footprint components ("carbon land"is considered a distinct Footprint component for which there is currently no biocapacity explicitly set aside). These components of demand and supply are added together to obtain an aggregate Ecological Footprint or biocapacity estimate.

Cropland

Growing crops for food, animal feed, fibre, and oils requires cropland, the land type with the greatest average bioproductivity per hectare. The FAO estimates that there are roughly 1.5 billion hectares of cropland worldwide as of 2003. The National Footprint Accounts use FAO harvest and area data for more than 70 major crops to calculate the area of cropland needed to produce a given quantity of crop product. As described in previous sections, the accounts do not track activities that decrease the long-term productivity of cropland such as soil degradation, erosion, or salination. While these processes will be reflected in future decreases in biocapacity, this decrease is not currently allocated to the activities producing this degradation today.

Grazing land

Raising animals for meat, hides, wool, and milk can entail the use of feed products grown on cropland, fishmeal from wild or farmed fish, and/or range land area for grazing. Worldwide, there are approximately 3.5 billion hectares of natural and semi-natural grassland and pasture. To calculate the grazing land Ecological Footprint of a livestock product, diet profiles are created to determine the mix of concentrate feed, cropped grasses, and grazed grasses consumed by that type of livestock. The area of grazing land demanded by a livestock product is calculated by using the amount of pasture grass that is needed to meet the total feed requirements of that product, after subtracting the other sources of feed used.

Fishing grounds

Harvesting fish and other marine products requires productive freshwater and marine fishing grounds. More than 95 per cent of marine fish catch is located on continental shelves, which, excluding inaccessible or unproductive waters, total 1.9 billion hectares. Marine areas outside continental shelves are currently excluded from Ecological Footprint accounts. Inland waters comprises an additional 0.4 billion hectares of available fishing grounds.

Catch data from the UN's Food and Agriculture Organization are used to estimate demand on fishing grounds, which is compared to an aggregate potential supply estimate of 93 million tonnes per year. Current accounts track both fish catch for direct human consumption and catch for fishmeal. An adjustment for bycatch is added to each country's reported annual catch.

Forest area

Harvesting timber products and fuelwood requires natural or plantation forests. Approximately 3.9 billion hectares of forests are available worldwide. The productivity of these forests is estimated using a variety of sources, primarily the Temperate and Boreal Forest Resource Assessment (TBFRA) and the Global Fibre Supply Model (GFSM). Consumption of roundwood and wood fuel are tracked along with four processed products-sawnwood, wood-based panels, paper and paperboard, and wood pulp.

Built-up land

Infrastructure for housing, transportation, and industrial production occupies built-up land. This space is the most poorly documented of all land use types, since the low-resolution satellite images available for most areas are not able to capture dispersed infrastructure and roads. Best estimates indicate a global total of 0.2 billion hectares of built-up land. Built-up land is assumed to have replaced cropland, as human settlements are predominantly located in the most fertile areas of a country.

Areas occupied by hydroelectric dams and reservoirs, used for the production of hydropower, are also counted within built-up land. The hydropower Footprint is calculated for each country using the average ratio of power output to inundated reservoir area for a selection of large dams for which both surface area and power output data are available.

"Carbon land"

Humans add carbon dioxide to the atmosphere in a number of ways, including through the burning of fossil fuels. Several natural cycles remove carbon dioxide from the atmosphere, including ocean absorption and uptake of carbon dioxide by plants during photosynthesis. The Ecological Footprint of fossil fuel consumption is calculated by estimating the biologically productive area needed to assimilate this waste product of the human economy. In this calculation, the accounts first subtract an estimated 1.8 Giga tonnes of carbon that are sequestered by the oceans every year (IPCC 2001). Potential negative impacts of this absorption on marine biocapacity are not included in current accounts.

The biologically productive area required to absorb the carbon dioxide not sequestered by the oceans is then calculated using the carbon absorption potential of world average forest. Sequestration capacity changes with both the maturity and composition of forests and with possible shifts in bioproductivity due to higher atmospheric carbon dioxide levels. An alternate method, not employed in current accounts, would be to calculate sequestration based on the carbon absorption potential of world average bioproductive land, rather than just forests. As forests are understood to be the most efficient of all land types at long term sequestration of carbon, a method using world average land would result in a larger total carbon Footprint.

Estimates of the land required to produce biomass energy equivalent to fossil fuels yield similar, but larger, Carbon Footprints than the waste assimilation approach. Other possible methods for accounting for fossil fuel use include calculating the past biocapacity embodied in fossil fuels, which would result in significantly larger Footprint estimates.

Pending further research, each unit of energy produced by nuclear power is currently counted as equal in Footprint to a unit of energy produce by burning fossil fuels. The carbon dioxide added to the atmosphere by human-induced land disturbances, such as slash-and-burn agricultural practices, is not currently accounted for in the Ecological Footprint, nor are the emissions of greenhouse gases other than carbon dioxide.

Embodied energy is the energy used during a product's entire life cycle in order to manufacture, transport, use and dispose of the product. The embodied energy in more than 600 categories of products is used with trade flows from the UN's COMTRADE database to generate estimates of the embodied carbon Footprint in traded goods.

Calculating a Global Hectare

In order to express Ecological Footprint results in a single measurement unit, global hectares, Ecological Footprint accounting normalizes different types of areas to account for differences in land and sea productivity. Equivalence factors and yield factors are used to convert actual areas in hectares of different land types into their equivalent numbers of global hectares. Equivalence and yield factors are applied to both Footprint and biocapacity calculations.

Equivalence factors translate a specific land type (i.e. cropland, pasture, forest, fishing ground) into a universal unit of biologically productive area, a global hectare. In 2003, for example, primary cropland had an equivalence factor of 2.21 (Table 4), indicating that primary cropland was more than twice as productive as a hectare of land with world average productivity. This same year, pasture had an equivalence factor of 0.49, showing that pasture was approximately half as productive as the average bioproductive hectare.

The equivalence factor for built land is equal to that for cropland (see Section 5). Equivalence factors are calculated on a yearly basis.

Yield factors account for the difference in production of a given land type across different nations. A hectare of pasture in New Zealand, for example, produces more meat on average than a hectare of pasture in Jordan. These differences may be due to natural factors, such as precipitation or soil quality, or management practices. To account for these differences, the yield factor compares the production of a specific land type in a nation to a world average hectare of the same land type. Each country and each year has its own set of yield factors. For example, Table 7 shows that, hectare by hectare, New Zealand's pastures are 2.5 times as productive as world average pastures. The yield factor for built land is assumed to be the same as that for cropland (see Section 5).

Area Type	Equivalence Factor [gha/ha]
Primary Cropland	2.21
Forest	1.34
Grazing Land	0.49
Marine	0.36
Inland Water	0.36
Built	2.21

Table 2: Equivalence Factors, 2003.

Communicating Results: Ecological Deficits and Reserves

An **ecological deficit** represents the amount by which the Ecological Footprint of a population exceeds the available biocapacity of that population's territory in a given year. A national ecological deficit measures the amount by which a country's Footprint exceeds its biocapacity. A nation can operate its economy with an ecological deficit by importing biocapacity from other nations, by placing demands on the global commons (e.g., carbon stocks in the atmosphere, fishing in international waters), or by depleting its own domestic ecological assets. A global ecological deficit, however, cannot be offset through trade and inevitably leads to the depletion of ecological assets and/or the accumulation of wastes. The global ecological deficit is thus equivalent to the annual global overshoot.

Populations with an Ecological Footprint smaller than their available biocapacity run an **ecological reserve**, the opposite of an ecological deficit. A nation's ecological reserve is not necessarily unused, however but may be occupied by the Footprints of other countries that import biocapacity from that nation. Countries may also choose to reserve this biocapacity for wild species or use by future generations.

Ecological debt is the sum of annual ecological deficits that have accumulated over a period of time. The current global ecological debt can be expressed as the number of "planet-years"of ecological deficit

	Primary cropland	Forest	Grazing Land	Ocean Fisheries
World average yield	1.0	1.0	1.0	1.0
Algeria	0.6	0.0	0.7	0.8
Guatemala	1.0	1.4	2.9	0.2
Hungary	1.1	2.9	2.0	1.9
Japan	1.5	2.6	2.2	1.4
Jordan	1.0	0.0	0.4	0.8
Laos	0.8	0.2	2.7	1.0
New Zealand	2.2	2.5	2.5	0.2
Zambia	0.5	0.3	1.5	1.1

Table 3: Sample yield factors for selected countries, 2003. National yield factors are calculated as the ratio of a country's yield to world-average yield.

the planet accrued since humanity entered into overshoot in the 1980s. One planet-year equals the total productivity of useful biological materials by the Earth in a given year.

The Future: Shrink and Share Scenarios

The current state of global overshoot highlights the need for reducing humanity's Ecological Footprint in order to avoid persistent depletion and, potentially, collapse of global ecosystems. Paths for reducing overshoot will need to be agreed upon, and reductions will need to be shared amongst all individuals and nations, since all share the use of the global biosphere. One approach to meeting these goals is to "Shrink and Share" humanity's Ecological Footprint. Shrink means reducing humanity's Footprint so that the consumption of renewable resources does not exceed the regenerative capacity of Earth's productive ecosystems. This targeted reduction will need to consider whether a portion of the Earth's biocapacity should be allocated for the use of wild species and the preservation of biodiversity. Share refers to the way the Earth's biologically productive capacity is to be divided amongst individuals, nations, regions, and wild species.

The need to shrinking the world's Footprint is evidenced by the current state of global overshoot. Sharing implies that some regions or nations will need to reduce their Footprints, but allows the potential for others to increase their Footprints in order to meet basic standards of living. To remain within the global ecological budget on a limited planet and avoid the long-term depletion of ecological capital, increases in demand in some regions will need to be offset by corresponding reductions elsewhere. Neither the 'Shrink' nor the 'Share' paths suggested by Ecological Footprint analysis make claims about what should be, what is ethical, or what is appropriate. They simply provide information on possible paths that global society could choose to take in the future.

Increases in biocapacity could help reduce the gap between demand and supply. These increases could be brought about by adding to the Earth's total bioproductive area - irrigating deserts, for example, or by increasing the yields of existing bioproductive areas. These increases must be carefully managed since the resources required can cause an increase in Footprint and negative impacts on biodiversity.

Further discussion on Shrink and Share scenarios and analysis, including the framework, data, and methods, can be found in Lovink et al. 2004, the *Living Planet Report 2006* (WWF 2006), and Kitzes et al. (2007).

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