CALCULATION METHODOLOGY FOR THE NATIONAL FOOTPRINT ACCOUNTS, 2010 EDITION

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Advancing the Science of Sustainability

Calculation Methodology for the National Footprint Accounts, 2010 Edition

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This document builds on the foundational Ecological Footprint research and the previous methodology papers for the National Footprint Accounts (Rees 1992, Wackernagel and Rees, 1996; Wackernagel et al. 1997, Wackernagel et al. 1999a, b, Wackernagel et al. 2002, Monfreda et al. 2004, Wackernagel et al. 2005, Kitzes et al. 2007, Ewing et al. 2008).

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ABSTRACT

Human demand on ecosystem services continues to increase, and there are indications that this demand is outpacing the regenerative and absorptive capacity of the biosphere. For this reason the productivity of natural capital may increasingly become a limiting factor for the human endeavour. Therefore, metrics tracking human demand on, and availability of, regenerative and waste absorptive capacity within the biosphere are needed to track minimum sustainability conditions. Ecological Footprint analysis is an accounting framework relevant to this research question; it measures human appropriation of ecosystem products and services in terms of the amount of bioproductive land and sea area needed to supply these products and services. The area of land or sea available to serve a particular use is called biological capacity (biocapacity), and represents the biosphere's ability to meet human demand for material consumption and waste disposal. Ecological Footprint and biocapacity calculation covers six land use types: cropland, grazing land, fishing ground, forest land, built-up land, and the uptake land to accommodate the carbon Footprint. For each land use type, the demand for ecological products and services is divided by the respective yield to arrive at the Footprint of each land use type. Ecological Footprint and biocapacity are scaled with yield factors and equivalence factors to convert this physical land demanded to world average biologically productive land, usually expressed in global hectares (gha). This allows for comparisons between various land use types with differing productivities. The National Footprint Accounts calculate the Ecological Footprint and biocapacity for more than 200 countries and the world. According to the 2010 Edition of the National Footprint Accounts, humanity demanded the resources and services of 1.51 planets in 2007; such demand has increased 2.5 times since 1961. This situation, in which total demand for ecological goods and services exceeds the available supply for a given location, is known as overshoot. On the global scale, overshoot indicates that stocks of ecological capital may be depleting and/or that waste is accumulating.

INTRODUCTION

Humanity relies on ecosystem products and services including resources, waste absorptive capacity, and space to host urban infrastructure. Environmental changes such as deforestation, collapsing fisheries, and carbon dioxide (CO_2) accumulation in the atmosphere indicate that human demand may well have exceeded the regenerative and absorptive capacity of the biosphere. Careful management of human interaction with the biosphere is essential to ensure future prosperity and reliable metrics are thus needed for tracking the regenerative and waste absorptive capacity of the biosphere; assessing current ecological supply and demand as well as historical trends provides a basis for setting goals, identifying options for action, and tracking progress toward stated goals. The National Footprint Accounts aim to provide such a metric in a way that may be applied consistently across countries as well as over time.

In 1997, Mathis Wackernagel and his colleagues at the Universidad Anáhuac de Xalapa started the first systematic attempt to calculate the Ecological Footprint and biocapacity of nations (Wackernagel et al. 1997). Building on these assessments, Global Footprint Network initiated its National Footprint Accounts in 2003, with the most recent Edition issued in 2010.

The National Footprint Accounts quantify annual supply of and demand for ecosystem products and services in a static, descriptive accounting framework. It provides the advantage of monitoring in a combined way the impacts of anthropogenic pressures that are more typically evaluated independently (climate change, fisheries collapse, land degradation, land use change, food consumption, etc.). However, as with most aggregate indicators, it has the drawback of implying a greater degree of additivity and interchangeability between the included land use types than is probably realistic.

The demand that populations and activities place on the biosphere in a given year - with prevailing technology and resource management of that year – is the Ecological Footprint. The supply created by the biosphere, namely biological capacity (biocapacity), is a measure of the amount of biologically productive land and sea area available to provide the ecosystem services that humanity consumes – our ecological budget (Wackernagel et al., 2002).

The 2010 Edition of the National Footprint Accounts calculate the Ecological Footprint and biocapacity of more than 200 countries and territories, as well as global totals, from 1961 to 2007 (Global Footprint Network 2010). The intent of the National Footprint Accounts is to provide scientifically robust and transparent calculations allowing for comparisons of countries' demands on global regenerative and absorptive capacity.

The calculations in the National Footprint Accounts are based primarily on international data sets published by the Food and Agriculture Organization of the United Nations (FAOSTAT, 2010), the UN Statistics Division (UN Commodity Trade Statistics Database – UN Comtrade 2010), and the International Energy Agency (IEA 2010). Other data sources include studies in peer-reviewed science journals and thematic collections—a complete list of source data sets is included in the Ecological Footprint Atlas 2010 (Ewing et al. 2010).

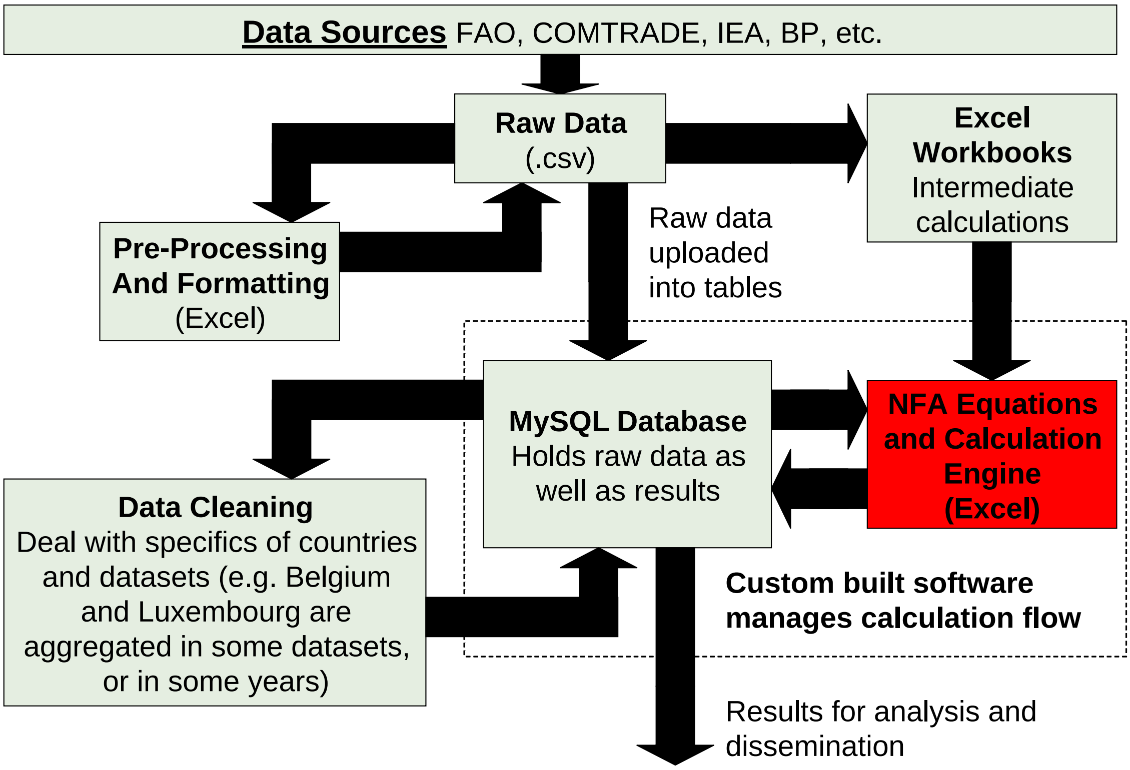

Figure 1 *Outline of NFA 2010 implementation.*

The above illustration represents the various information processing steps performed in calculating the National Footprint Accounts. 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 either in a MySQL database, or in an Excel workbook. Further data pre-processing is then performed by excecuting scripts within the database environment. The NFA calculations themselves are maintained in an Excel workbook, which references the supporting workbook. A custom built software application manages the importation of data from the database into the NFA workbook, and writes NFA results back to a table in the database. The implementation of the National Footprint Accounts is described in detail in the *Guidebook to the National Footprint Accounts 2010* (Kitzes et al. 2010). The Accounts are maintained and updated by Global Footprint Network with the support of approximately 100 Partner Organizations.

This paper describes the methodology for calculating the Ecological Footprint and biocapacity utilized in the 2010 Edition of the National Footprint Accounts and provides researchers and practitioners with information to deepen their understanding of the calculation methodology. This research builds on the foundational Ecological Footprint works and the previous methodology papers for the National Footprint Accounts (Rees 1992, Wackernagel and Rees, 1996; Wackernagel et al. 1997, Wackernagel et al. 1999a, b, Wackernagel et al. 2002, Monfreda et al. 2004, Wackernagel et al. 2005, Kitzes et al. 2007, Ewing et al. 2008).

FUNDAMENTAL ASSUMPTIONS OF ECOLOGICAL FOOTPRINT ACCOUNTING

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

- The majority of the resources people consume and the wastes they generate can be quantified and tracked.
- An important subset 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 each global hectare in any given year represents 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.

FOOTPRINT AND BIOCAPACITY CALCULATIONS

The Ecological Footprint measures appropriated biocapacity, expressed in global average bioproductive hectares, across five distinct land use types, in addition to one category of indirect demand for biocapacity in the form of absorptive capacity for carbon dioxide emissions. The Ecological Footprint of production, EF_P, represents primary demand for biocapacity and is calculated as

$$\mathrm{EF_P} = \frac{P}{\mathrm{Y_N}} \cdot YF \cdot EQF$$

(Equation 1)

where P is the amount of a product harvested or carbon dioxide emitted, Y_N is the national average yield for P (or its carbon uptake capacity), and YF and EQF are the yield factor and equivalence factor, respectively, for the land use type in question. Yield factors capture the difference between local and world average productivity for usable products within a given land use type. They are calculated as the ratio of national average to world average yields and thus vary by country, land use type, and year within the National Footprint Accounts. Equivalence factors translate the area of a specific land use type available or demanded into units of world average biologically productive area. Thus, it varies by land use type and year. Equivalence factors are calculated as the ratio of the maximum potential ecological productivity of world average land of a specific land use type (e.g. cropland) and the average productivity of all biologically productive lands on Earth.

All manufacturing processes rely to some degree on the use of biocapacity, to provide material inputs and remove wastes at various points in the production chain. Thus all products carry with them an embodied Footprint and international trade flows can be seen as flows of embodied demand for biocapacity.

In order to keep track of both the direct and indirect biocapacity needed to support people's consumption patterns, the Ecological Footprint methodology uses a consumer-based approach; for each land use type, the Ecological Footprint of consumption (EF_C) is thus calculated as

$$EF_C = EF_P + EF_I - EF_E \qquad \text{(Equation 2)}$$

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. The National Footprint Accounts calculate the Footprint of apparent consumption, as data on stock changes for various commodities are generally not available. One of the advantages of calculating Ecological Footprints at the national level is that this is the level of aggregation at which detailed and consistent production and trade data are most readily available. Such information is essential in properly allocating the Footprints of traded goods to their final consumers.

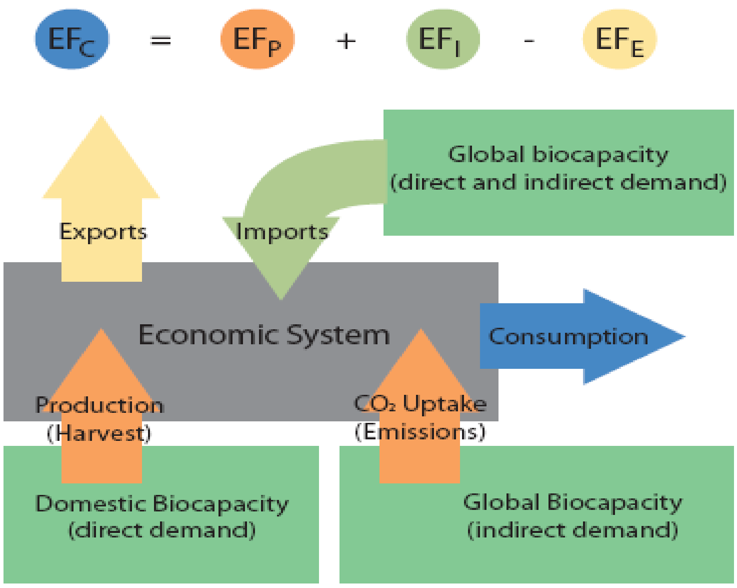

Figure 2 *Schematic of Direct and Indirect Demand for Domestic and Global Biocapacity.*

Derived Products

Ecological Footprint assessments aim to measure demand for biocapacity by final demand, but the Ecological Footprint is tallied at the point of primary harvest or carbon emission. Thus, tracking the embodied Ecological Footprint in derived products is central to the task of assigning the Ecological Footprint of production to the end uses it serves.

Primary and derived goods are related by product specific extraction rates. The extraction rate for a derived product, $EXTR_D$, is used to calculate its effective yield as follows:

$$Y_D = Y_P \cdot EXTR_D \qquad \text{(Equation 3)}$$

where Y_P and Y_D are the yield for the primary product, and the effective yield for the derived product, respectively.

Often $EXTR_D$ is simply the mass ratio of derived product to primary input required. This ratio is known as the technical conversion factor (FAO, 2000a) for the derived product, denoted TCF_D below. There are a few cases where multiple derived products are created simultaneously from the same primary product. For example, soybean oil and soybean cake are both extracted simultaneously from the same primary product, in this case soybean. In this situation, summing the primary product equivalents of the derived products would lead to double counting. To resolve this problem, the Ecological Footprint of the primary product must be shared between the simultaneously derived goods. The generalized formula for the extraction rate for a derived good *D* is

$$EXTR_D = \frac{TCF_D}{FAF_D} \qquad \text{(Equation 4)}$$

where FAF_D is the Footprint allocation factor. This allocates the Footprint of a primary product between simultaneously derived goods according to the TCF-weighted prices. The prices of derived goods represent their relative contributions to the incentive for the harvest of the primary product. The equation for the Footprint allocation factor of a derived product is

$$FAF_D = \frac{TCF_D V_D}{\sum TCF_i V_i} \qquad \text{(Equation 5)}$$

where V_i is the market price of each simultaneous derived product. For a production chain with only one derived product, then, FAF_D is 1 and the extraction rate is equal to the technical conversion factor.

A country's biocapacity *BC* for any land use type is calculated as follows:

$$BC = A \cdot YF \cdot EQF \qquad \text{(Equation 6)}$$

where *A* is the area available for a given land use type and *YF* and *EQF* are the yield factor and equivalence factor, respectively, for the country, year, and land use type in question.

NORMALIZING BIOPRODUCTIVE AREAS – FROM HECTARES TO GLOBAL HECTARES

Average bioproductivity differs between various land use types, as well as between countries for any given land use type. For comparability across countries and land use types, Ecological Footprint and biocapacity are usually expressed in units of world-average bioproductive area. Expressing Footprints in world-average hectares also facilitates tracking the embodied bioproductivity in international trade flows, as *g*ha measure the ecological productivity required to maintain a given flow. Global hectares provide more information than simply weight - which does not capture the extent of land and sea area used - or physical area - which does not capture how much ecological production is associated with that land. Yield factors and equivalence factors are the two coefficients needed to express results in terms of global hectares (Monfreda et al., 2004; Galli et al., 2007), thus providing comparability between various countries' Ecological Footprint as well as biocapacity values.

Yield Factors

Yield factors account for countries' differing levels of productivity for particular land use types.[1] Yield factors are country-specific and vary by land use type and year. They may reflect natural factors such as differences in precipitation or soil quality, as well as anthropogenic induced differences such as management practices.

The yield factor is the ratio of national average to world average yields. It is calculated in terms of the annual availability of usable products. For any land use type *L*, a country's yield factor YF_L, is given by

[1] For example, the average hectare of pasture in New Zealand produces more grass than a world average hectare of pasture land. Thus, in terms of productivity, one hectare of grassland in New Zealand is equivalent to more than one world average grazing land hectare; it is potentially capable of supporting more meat production. Table 1 shows the yield factors calculated for several countries in the 2010 Edition of Global Footprint Network's National Footprint Accounts.

$$YF_L = \frac{\sum_{i \in U} A_{W,i}}{\sum_{i \in U} A_{N,i}} \qquad \text{(Equation 7)}$$

where U is the set of all usable primary products that a given land use type yields, and $A_{W,i}$ and $A_{N,i}$ are the areas necessary to furnish that country's annually available amount of product i at world and national yields, respectively. These areas are calculated as

$$A_{N,i} = \frac{P_i}{Y_N} \text{ and } A_{W,i} = \frac{P_i}{Y_W} \qquad \text{(Equation 8)}$$

where P_i is the total national annual growth of product i and Y_N and Y_W are national and world yields, respectively. Thus $A_{N,i}$ is always the area that produces i within a given country, while $A_{W,i}$ gives the equivalent area of world-average land yielding i.

With the exception of cropland, all other land use types included in the National Footprint Accounts provide only a single primary product, such as wood from forest land or grass from grazing land. For these land use types, the equation for the yield factor simplifies to

$$YF_L = \frac{Y_N}{Y_W} \qquad \text{(Equation 9)}$$

Due to the difficulty of assigning a yield to built-up land, the yield factor for this land use type is assumed to be the same as that for cropland (in other words urban areas are assumed to be built on or near productive agricultural lands). For lack of detailed global datasets, areas inundated by hydroelectric reservoirs are presumed to have previously had world average productivity. The yield factor for carbon uptake land is assumed to be the same as that for forest land, due to limited data availability regarding the carbon uptake of other land use types. All inland waters are assigned yield factors of one, due to the lack of a comprehensive global dataset on freshwater ecosystem productivities.

Yield	Cropland	Forest	Grazing Land	Fishing Grounds
World Average	**1.0**	**1.0**	**1.0**	**1.0**
Algeria	0.3	0.4	0.7	0.9
Germany	2.2	4.1	2.2	3.0
Hungary	1.1	2.6	1.9	0.0
Japan	1.3	1.4	2.2	0.8
Jordan	1.1	1.5	0.4	0.7
New Zealand	0.7	2.0	2.5	1.0
Zambia	0.2	0.2	1.5	0.0

Table 1: *Sample Yield Factors for Selected Countries, 2007.*

Equivalence Factors

In order to combine the Ecological Footprints or biocapacities of different land use types, a second coefficient is necessary. Equivalence factors convert the areas of different land use types, at their respective world average productivities, into their equivalent areas at global average bioproductivity across all land use types. Equivalence factors vary by land use type as well as by year.

The rationale behind Equivalence factors' calculation is to weight different land areas in terms of their capacity to produce resources useful for humans. The weighting criterion is therefore not just the quantity of biomass produced, but also the quality of such biomass, meaning how valuable this biomass is for humans. Net Primary Production (NPP) values have been suggested for use in scaling land type productivity (Venetoulis and Talberth, 2008); however this would not allow incorporating the "quality" criterion in the scaling procedure. Usable NPP data could theoretically be used as weighting factors as they would allow to track both the quantity and quality of biomass produced by land use types (Kitzes et al., 2009); however usable-NPP data availability and their use in calculating equivalence factors has not been tested yet by Global Footprint Network. As such, equivalence factors are currently calculated using suitability indexes from the Global Agro-Ecological Zones model combined with data on the actual areas of cropland, forest land, and grazing land area from FAOSTAT (FAO and IIASA Global Agro-Ecological Zones 2000 FAO ResourceSTAT Statistical Database 2007). The GAEZ model divides all land globally into five categories, based on calculated potential crop productivity. All land is assigned a quantitative suitability index from among the following:

- Very Suitable (VS) – 0.9
- Suitable (S) – 0.7
- Moderately Suitable (MS) – 0.5
- Marginally Suitable (mS) – 0.3
- Not Suitable (NS) – 0.1

The calculation of the equivalence factors assumes that within each country the most suitable land available will be planted to cropland, after which the most suitable remaining land will be under forest land, and the least suitable land will be devoted to grazing land. The equivalence factors are calculated as the ratio of the world average suitability index for a given land use type to the average suitability index for all land use types. Figure 3 shows a schematic of this calculation.

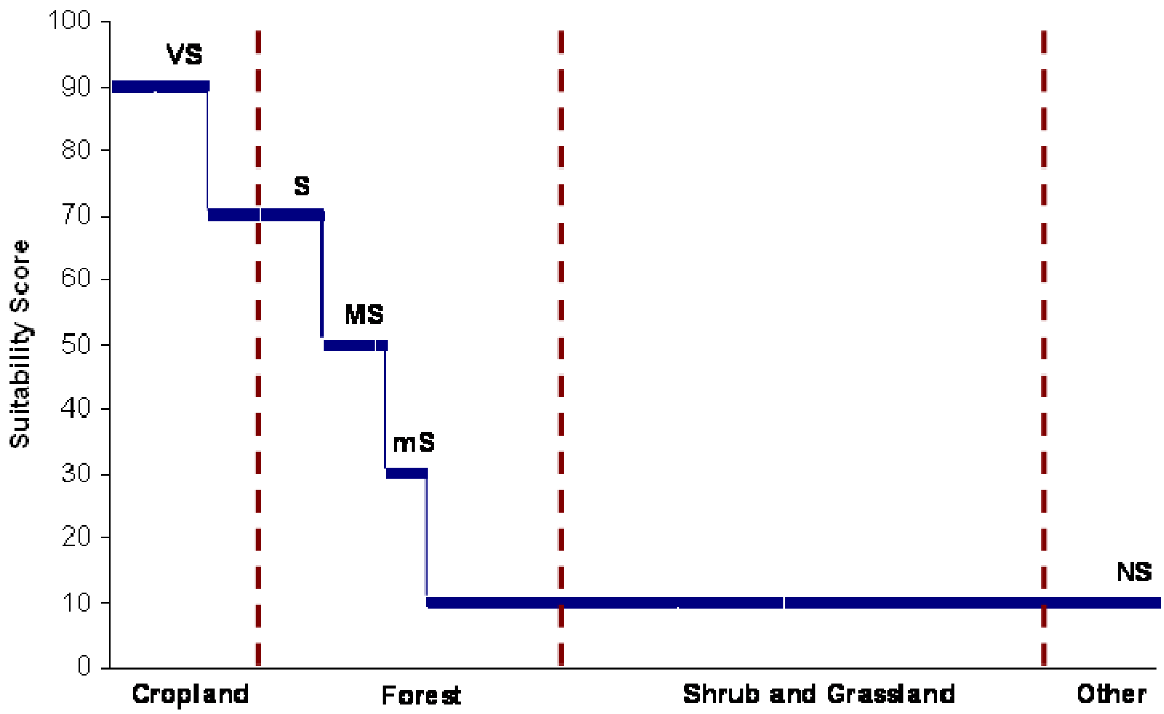

Figure 3 *Schematic Representation of Equivalence Factor Calculations.* The total number of bioproductive land hectares is shown by the length of the horizontal axis. Vertical dashed lines divide this total land area into the three terrestrial land use types for which equivalence factors are calculated (cropland, forest, and grazing land). The length of each horizontal bar in the graph shows the total amount of land available with each suitability index. The vertical location of each bar reflects the suitability score for that suitability index, between 10 and 90.

For the same reasons detailed above, the equivalence factor for built-up land is set equal to that for cropland, while that of carbon uptake land is set equal to that of forest land. The equivalence factor for hydroelectric reservoir area is set equal to one, reflecting the assumption that hydroelectric reservoirs flood world average land. The equivalence factor for marine area is calculated such that a single global hectare of pasture will produce an amount of calories of beef equal to the amount of calories of salmon that can be produced by a single global hectare of marine area. The equivalence factor for inland water is set equal to the equivalence factor for marine area.

Table 2 shows the equivalence factors for the land use types in the 2010 National Footprint Accounts, data year 2007.

Area Type	Equivalence Factor [global hectares per hectare]
Cropland	2.51
Forest	1.26
Grazing Land	0.46
Marine & Inland Water	0.37
Built-up Land	2.51

Table 2: *Equivalence Factors, 2007.* Cropland's equivalence factor of 2.51 indicates that world-average cropland productivity was more than double the average productivity for all land combined. This same year, grazing land had an equivalence factor of 0.46, showing that grazing land was, on average, 46 per cent as productive as the world-average bioproductive hectare.

LAND USE TYPES IN THE NATIONAL FOOTPRINT ACCOUNTS

The Ecological Footprint represents demand for ecosystem products and services in terms of these land use types, while biocapacity represents the productivity available to serve each use. In 2007, the area of biologically productive land and water on Earth was approximately 12 billion hectares. After multiplying by the equivalence factors, the relative area of each land use type expressed in global hectares differs from the distribution in actual hectares as shown in Figure 4.

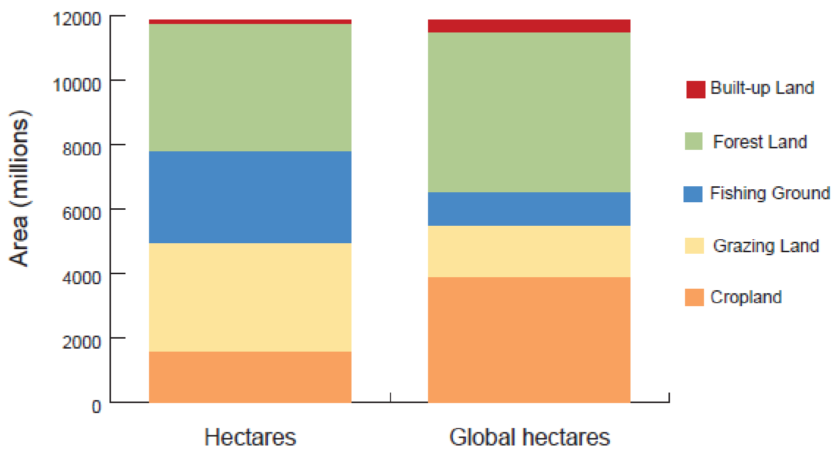

Figure 4: *Relative area of land use types worldwide in hectares and global hectares, 2007.*

The Accounts are specifically designed to yield conservative estimates of global overshoot as Footprint values are consistently underestimated while actual rather than sustainable biocapacity values are used. For instance, human demand, as reported by the Ecological Footprint, is underestimated because of the exclusion of freshwater consumption, soil erosion, GHGs emissions other than CO_2 as well as impacts for which no regenerative capacity exists (e.g. pollution in terms of waste generation, toxicity, eutrophication, etc.). In turn, biosphere's supply is overestimated as both the land degradation and the long term sustainability of resource extraction is not taken into account.

Cropland

Cropland consists of the area required to grow all crop products, including livestock feeds, fish meals, oil crops and rubber. It is the most bioproductive of the land use types included in the National Footprint Accounts. In other words the number of global hectares of cropland is large compared to the number of physical hectares of cropland in the world, as shown in Figure 4.

Worldwide in 2007 there were 1.55 billion hectares designated as cropland (FAO ResourceSTAT Statistical Database 2007). The National Footprint Accounts calculate the Footprint of cropland according to the production quantities of 164 different crop categories. The Footprint of each crop type is calculated as the area of cropland that would be required to produce the harvested quantity at world-average yields.

Cropland biocapacity represents the combined productivity of all land devoted to growing crops, which the cropland Footprint cannot exceed. As an actively managed land use type, cropland has yields of harvest equal to yields of growth by definition and thus it is not possible for the Footprint of production of this land use type to exceed biocapacity within any given area (Kitzes et al., 2009b). The eventual availability of data on present and historical sustainable crop yields would allow improving the cropland footprint calculation and tracking crop overexploitation.

Grazing Land

The grazing land Footprint measures the area of grassland used in addition to crop feeds to support livestock. Grazing land comprises all grasslands used to provide feed for animals, including cultivated pastures as well as wild grasslands and prairies, In 2007, there were 3.38 billion hectares of land worldwide classified as grazing land (FAO ResourceSTAT Statistical Database 2007). The grazing land Footprint is calculated following Equation 1, where yield represents average above-ground NPP for grassland. The total demand for pasture grass, P_{GR}, is the amount of biomass required by livestock after cropped feeds are accounted for, following the formula

$$P_{GR} = TFR - F_{Mkt} - F_{Crop} - F_{Res} \qquad \text{(Equation 10)}$$

where TFR is the calculated total feed requirement, and F_{Mkt}, F_{Crop} and F_{Res} are the amounts of feed available from general marketed crops, crops grown specifically for fodder, and crop residues, respectively.

Since the yield of grazing land represents the amount of above-ground primary production available in a year, and there are no significant prior stocks to draw down, overshoot is not physically possible over extended periods of time for this land use type. For this reason, a country's grazing land Footprint of production is prevented from exceeding its biocapacity in the National Footprint Accounts.

The grazing land calculation is the most complex in the National Footprint Accounts and significant improvements have taken place over the past seven years; including improvements to the total feed requirement, inclusion of fish and animal products used as livestock feed, and inclusion of livestock food aid (Ewing et al. 2010; see also the appendix to this paper).

Fishing Grounds

The fishing grounds Footprint is calculated based on the annual primary production required to sustain a harvested aquatic species. This primary production requirement, denoted *PPR*, is the mass ratio of harvested fish to annual primary production needed to sustain that species, based on its average trophic level. Equation 11 provides the formula used to calculate *PPR*. It is based on the work of Pauly and Christensen (1995).

$$PPR = CC \cdot DR \cdot \left(\frac{1}{TE}\right)^{(TL-1)} \qquad \text{(Equation 11)}$$

where *CC* is the carbon content of wet-weight fish biomass, *DR* is the discard rate for bycatch, *TE* is the transfer efficiency of biomass between trophic levels, and *TL* is the trophic level of the fish species in question.

In the National Footprint Accounts, *DR* is assigned the global average value of 1.27 for all fish species, meaning that for every tonne of fish harvested, 0.27 tonnes of bycatch are also harvested (Pauly and Christensen 1995). This bycatch rate is applied as a constant coefficient in the PPR equation, embodying the assumption that the trophic level of the bycatch is the same as that of the primary catch species. These approximations are employed for lack of higher resolution data on bycatch. *TE* is assumed to be 0.1 for all fish, meaning that 10% of biomass is transferred between successive trophic levels (Pauly and Christensen 1995).

The estimate of annually available primary production used to calculate marine yields is based on estimates of the sustainable annual harvests of 19 different aquatic species groups (Gulland 1971). These quantities are converted to a primary production equivalents using Eq 11 and the sum of these is taken to be the total primary production requirement which global fisheries may sustainably harvest. Thus the total sustainably harvestable primary production requirement, PP_S, is calculated as

$$PP_S = \sum \left(Q_{S,i} \cdot PPR_i\right) \qquad \text{(Equation 12)}$$

where $Q_{S,i}$ is the estimated sustainable catch for species group *i*, and PPR_i is the PPR value corresponding to the average trophic level of species group *i*. This total harvestable primary production requirement is allocated across the continental shelf areas of the world to produce biocapacity estimates. Thus the world-average marine yield Y_M, in terms of PPR, is given by

$$Y_M = \frac{PP_S}{A_{CS}} \qquad \text{(Equation 13)}$$

where PP_S is the global sustainable harvest from Equation 12, and A_{CS} is the global total continental shelf area.

The fishing grounds calculation is one of the most complex in the National Footprint Accounts and significant improvements have taken place over the past seven years; including revision of many fish extraction rates, inclusion of aquaculture production, and inclusion of crops used in aquafeeds (Ewing et al. 2010; see also the appendix to this paper).

Forest Land

The forest land Footprint measures the annual harvests of fuelwood and timber to supply forest products. Worldwide in 2007 there were 3.94 billion hectares of forest land area in the world (FAO ResourceSTAT Statistical Database 2007).[2]

The yield used in the forest land Footprint is the net annual increment of merchantable timber per hectare. Timber productivity data from the UNEC and FAO Forest Resource Assessment and the FAO Global Fiber Supply are utilized to calculate the world average yield of 1.81 m^3 of harvestable wood per hectare per year (UNEC, 2000, FAO 2000b, FAO 1998).

The National Footprint Accounts calculate the Footprint of forest land according to the production quantities of 13 primary timber products and three wood fuel products. Trade flows include 30 timber products and three wood fuel products.

[2] Due to data limitation, current accounts do not distinguish between forests for forest products, for long-term carbon uptake, or for biodiversity reserves.

Carbon Footprint

The uptake land to accommodate the carbon Footprint is the only land use type included in the Ecological Footprint which is exclusively dedicated to tracking a waste product: carbon dioxide.[3] In addition, it is the only land use type for which biocapacity is not explicitly defined.

CO_2 is released into the atmosphere from a variety of sources, including human activities such as burning fossil fuels and certain land use practices; as well as natural events such as forest fires, volcanoes, and respiration by animals and microbes.

Many different ecosystem types have the capacity for long-term storage of CO_2, including the land use types considered in the National Footprint Accounts such as cropland or grassland. However, since most terrestrial carbon uptake in the biosphere occurs in forests, and to avoid overestimations, carbon uptake land is assumed to be forest land by the Ecological Footprint methodology. For this reason it is considered to be a subcategory of forest land. Therefore, in the 2010 Edition, forest for timber and fuelwood is not separated from forest for carbon uptake.[4]

Carbon uptake land is the largest contributor to humanity's current total Ecological Footprint and increased more than tenfold from 1961 to 2007. However, in lower income countries the carbon Footprint is often not the dominant contributor to the overall Ecological Footprint.

Analogous to Equation 1b, the formula for the carbon Footprint EF_c is

$$EF_C = \frac{P_C \cdot (1 - S_{Ocean})}{Y_C} * EQF \qquad \text{(Equation 14)}$$

where P_C is annual emissions (production) of carbon dioxide, S_{Ocean} is the fraction of anthropogenic emissions sequestered by oceans in a given year and Y_C is the annual rate of carbon uptake per hectare of forest land at world average yield.

Built-Up Land

The built-up land Footprint is calculated based on the area of land covered by human infrastructure: transportation, housing, industrial structures and reservoirs for hydroelectric power generation. In 2007, the built-up land area of the world was 169.59 million hectares. The 2010 Edition of the National Footprint Accounts assumes that built-up land occupies what would previously have been cropland. This assumption is based on the observation that human settlements are generally situated in fertile areas with the potential for supporting high yielding cropland (Wackernagel et al. 2002).

For lack of a comprehensive global dataset on hydroelectric reservoirs, the National Footprint Accounts assume these to cover areas in proportion to their rated generating capacity. Built-up land always has a biocapacity equal to its Footprint since both quantities capture the amount of bioproductivity lost to encroachment by physical infrastructure. In addition, the Footprint of production and the Footprint of consumption of built-up land are always equal in National Footprint Accounts as built-up land embodied in traded goods is not currently included in the calculation due to lack of data. This omission is likely to cause overestimates of the built-up Footprint of exporting countries and underestimates of the built-up Footprint of importing countries.

[3] Today, the term "carbon footprint" is widely used as shorthand for the amount of anthropogenic greenhouse gas emissions; however, in the Ecological Footprint methodology, it rather translates the amount of anthropogenic carbon dioxide into the amount of productive land and sea area required to sequester carbon dioxide emissions.

[4] Global Footprint Network has not yet identified reliable global data sets on how much of the forest areas are dedicated to long-term carbon uptake. Hence, the National Footprint Accounts do not distinguish which portion of forest land is dedicated to forest products and how much is permanently set aside to provide carbon uptake services. Also note that other kind of areas might be able to provide carbon uptake services.

CONCLUSION

In an increasingly resource constrained world, accurate and effective resource accounting tools are needed if nations, cities and companies want to stay competitive. The Ecological Footprint is one such resource accounting tool, designed to track human demand on the regenerative and absorptive capacity of the biosphere.

In 1961, the first year for which the National Footprint Accounts are available, humanity's Ecological Footprint was approximately half of what the biosphere could supply—humanity was living off the planet's annual ecological interest, not drawing down its principal (Figure 5). According to the 2010 Edition of the National Footprint Accounts, human demand first exceeded the planet's biocapacity in mid 1970s. Since 1961, overall humanity's Footprint has more than doubled and overshoot has continued to increase, reaching 51% in 2007. The various land use types are stacked to show the total Ecological Footprint. Humanity's Ecological Footprint in 2007 consisted of 22% cropland, 8% grazing land, 11% forest land, 4% fishing ground, 54% carbon uptake land, and 2% built-up land. As these annual deficits accrue into an ever larger ecological debt, ecological reserves are depleting, and wastes such as CO_2 are accumulating in the biosphere and atmosphere.

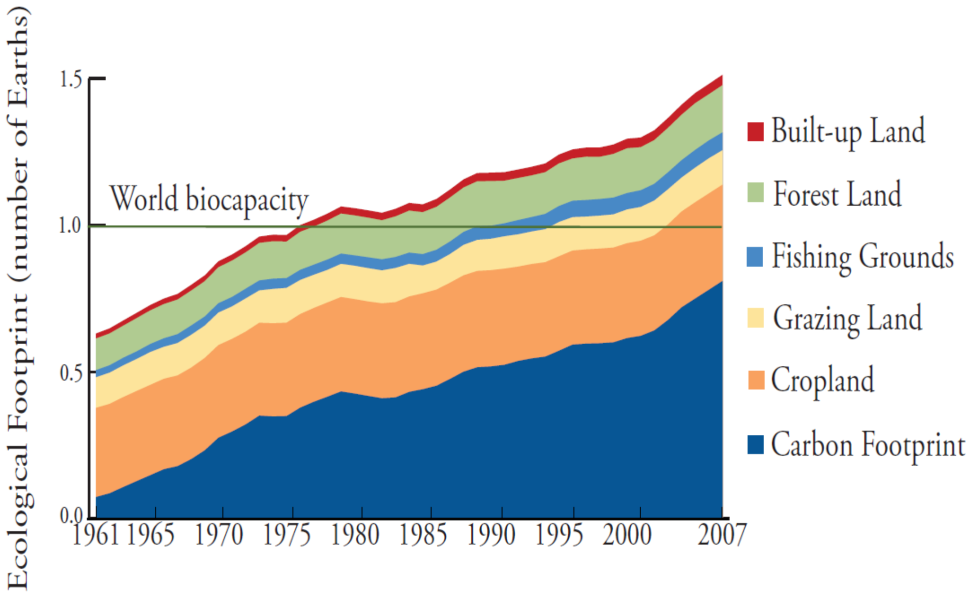

Figure 5: *World overshoot according to the 2010 Edition of the National Footprint Accounts.* Humanity's Ecological Footprint, expressed in number of planets demanded, has increased significantly over the past 47 years.

This paper has described the fundamental principles and calculations utilized in the 2010 Edition of the National Footprint Accounts. To learn more about the structure and results of the 2010 Edition of the National Footprint Accounts, please visit Global Footprint Network's website to download the *Guidebook to the National Footprint Accounts: 2010 Edition* and *The Ecological Footprint Atlas 2010*. They are available at www.footprintnetwork.org/methodology.

APPENDIX: METHODOLOGICAL CHANGES BETWEEN THE 2008 AND 2010 EDITION OF NATIONAL FOOTPRINT ACCOUNTS

A formal process is in place to assure continuous improvement of the National Footprint Accounts (NFA) methodology. Coordinated by Global Footprint Network, this process is supported by its partners and by the National Footprint Accounts Review Committee, as well as other stakeholders.

There have been three primary motivations for revisions to the calculation method of the National Footprint Accounts:

- to adapt to changes in the organization of the source data;
- to respond to issues raised in outside reviews (e.g., DG Environment, 2008; Stiglitz et al., 2009; Wiedmann and Barrett, 2010; and the like); and
- to increase the specificity and accuracy of the NFA calculations.

Many of the changes in the latter category focus on incorporating country specific information in determining the Footprint intensities of traded goods. This appendix describes each of the calculation method changes implemented since the 2008 Edition of the NFA.

General Changes

Since the release of the 2008 NFA, there have been substantial revisions to some of the FAO datasets the NFA rely on. For example, the product classifications have changed, and in some instances the extended HS codes used previously have been replaced entirely by the FAO's own system of commodity classification.

In many of the datasets used to calculate the NFA, Belgium and Luxembourg are reported as an aggregate for most of the time series, and are only reported separately after 2000. In past editions, we have scaled the 2000 values for these two countries according to the change in their combined Footprint and biocapacity to approximate a time series for each prior to 2000. In the 2009 and 2010 Edition of the NFA we have split the reported production and trade amounts in the raw data where Belgium and Luxembourg are reported as an aggregate, using the ratio of their quantities in the earliest year where the two are reported separately. This is probably more accurate, since the split for each product is unaffected by the ratios of other products in the same land use category.

In the NFA 2010, a source data cleaning algorithm was implemented to reduce (1) spikes and troughs and (2) inconsistent reporting of source data sets. The algorithm involved interpolation to fill in data gaps and to exclude data points that are far out of the expected data range.

Cropland Changes

The product lists for crop production and trade have been changed to match changes in the categories reported in FAOSTAT. Previously, the FAO TradeSTAT database reported the sum of trade and food aid shipments. Food aid for cropland, livestock, and fish is now reported separately from other trade, necessitating the addition of several worksheets in the NFA calculation workbook to explicitly calculate the embodied Footprint of food aid flows. Since food aid quantities are reported only for aggregate categories, the composition of each country's domestic production is used to determine the intensity of food aid exports.

In the NFA 2008, a world average un-harvested percentage was applied to each country's consumption quantity. This means unharvested crops were added as a universal "tax" to consumed crops. This led to each country's cropland Footprint of production not necessarily equaling its cropland biocapacity as it should, as well as a slight mismatch between production, trade quantities and consumption.

In the NFA 2010, a country specific un-harvested cropland percentage has been calculated, and applied to the yield factor calculation, as modifiers to the respective yields. Specifically, the sum of the land area harvested for each item in the FAO data base (reported per item with production) was subtracted from the total area for each land use type as reported by the FAO. This leads to a globally consistent Footprint/ton for crop products, consistent with products of other land use types, while maintaining the constraint that each country's cropland EFp is equal to its BC. The effect is that a larger national un-harvested area percentage appears as a lower biocapacity rather than a higher EFp.

Grazing Land Changes

The biggest change in the grazing land and livestock calculation is the modification of export Footprint intensities to better reflect a country's domestic feed mix. Previously (NFA 2008 Edition), all traded livestock products were assumed to embody world average cropland and grazing land demand. Already in the 2009 Edition of the NFA, these intensities were modified according to domestic mix and intensity of feed to estimate a country specific Footprint intensity of livestock. The exports intensity for livestock and livestock products was then calculated as the weighted average of production and imports intensities. This was done under the assumption that countries process some of the livestock that is imported, and export a product derived from these imports - as opposed to all imports being consumed within the country (e.g. sausage). Ideally imports would be country specific as well, but as of yet are not calculated similarly.

Several smaller additional changes have been also implemented in the 2010 Edition of the NFA:

- The list of livestock for which feed demand is calculated has been expanded, providing a more comprehensive picture of each country's livestock populations and feed intensity. The expanded list of livestock feed commodities now includes fish and other animal products.
- Feed intensities were calculated by accounting for the feed intake requirements and life span of different livestock animals. These feed intensities for animals were then allocated to the products that come from the animals. Previously (NFA 2008 and 2009 Editions), the feed intensity for all livestock products were considered to be the weight of feed required for the weight of product. These ratios were obtained from published data sources.
- The aggregate crop amounts used to determine residue feed availability are explicitly calculated from production quantities of each aggregate category's constituent crop products. This eliminates some potential for double-counting.
- A conversion factor between wet and dry weight for cropped grass feed has been removed after a review of reported yields in the ProdSTAT database indicated that no such conversion is necessary.
- Livestock and fish food aid shipments were also included.
- The livestock constants for live weight and total feed requirement (used to calculate the Footprint of trade) were revised due to a mismatch between annual feed and total feed requirement.

It is worth noting that the removal of the "Other Wooded Land" category (see 'Land Cover Changes') affects the grazing land Footprint by reducing many countries' grazing land Footprints of production. This is due to the fact that the current calculation method does not allow EFp for grazing to exceed biocapacity in the Footprint algorithm (assuming that this is physically not possible).

Fishing Grounds Changes

The FAO FishSTAT database does not report trade in fish commodities prior to 1976. In the NFA 2008, trade in fish commodities prior to 1976 was simply omitted. In both the 2009 and 2010 Editions of the NFA, COMTRADE data were used to extrapolate these trade flows back to the start of our time series (1961).

In the 2010 Edition of the NFA the list of fish species considered in the Footprint of production calculation has been expanded, as the number of reported species has grown, and estimates of average trophic level have been collected for more species. The exports yield for each fish commodity is now calculated as the weighted average of domestic catch and imports. The catch intensity for each commodity is now based on the effective trophic level across a country's catch of several species, rather than global constants based on the trophic levels of individual species. The formula for effective trophic level has also been revised to reflect the exponential relation between fish trophic levels and Footprint intensities (see guidebook for details).

Moreover, fishmeal and fish oil production and trade, and of aquaculture, were included in the 2010 Edition and the fish commodity extraction rates were revised to include species-specific extraction rates for all species.

Forest Land Changes

The biggest change in the forest land Footprint calculation is the modification of the forests' net annual increment (NAI) values used in the accounts. In the 2008 Edition of the NFA, NAI values for countries were calculated using the Temperate and Boreal Forest Resource Assessment (TBFRA) 2000 dataset. If these data were unavailable for a particular country then the country's NAI drawn from the Global Fibre Supply Model (GFSM) 1998 dataset was used. If these data were still unavailable, the world average NAI (calculated as the weighted average of NAI values for countries covered by the GFSM dataset) were allocated to that country.

The calculation of national net annual increments (NAI) was already refined for the 2009 Edition of the National Footprint Accounts and the new values have been also used in the 2010 Edition of the NFA. Refinement included using (where possible) regional rather than global averages for countries where explicit NAI estimates are lacking. This allows to more accurately account for countries with limited data availability. Moreover, the global average NAI is now calculated from national figures, rather than being reported independently. This has brought greater consistency between each country and the world average NAI values, as well as between countries' forest biocapacity and Footprint estimates.

Carbon Footprint Changes

In the NFA 2010, there were five substantial revisions to the carbon Footprint calculations:

- Use of CO_2 intensity of total primary energy supply, rather than only heat and electricity generation.
- Calculation of country-specific CO_2 intensities for energy supply, as a weighted average of production and imports.
- Inclusion of trade in electricity (using IEA data).
- Allocation of international transport emissions ("bunker fuels") according to each country's imports as a fraction of total global trade in units of mass (in the 2009 edition this was a "tax" applied to each country's production).
- Embodied energy data sets for many of the traded commodities in UN COMTRADE were revised to separate electricity inputs to production from other energy use. New values used in the 2010 Edition of the NFA were estimated using data from the University of Bath Inventory of Carbon and Energy (Hammond and Jones, 2008), Thormark (2002), Interfacultaire Vakgroep Energie en Milieukunde Energy Analysis Program (IVEM 1999), and a collection of LCA data from the Stockholm Environment Institute at York University. The use of these data sources is believed to increase the accuracy of the calculation; however this is also likely to cause relevant changes in countries' carbon Footprint values (2008 vs. 2010 Edition of the NFA).

Already in the NFA 2009, two minor adjustments to the carbon Footprint calculation were implemented: the CO_2 intensity time series estimation was imputed by following the % change in the most closely correlated countries, and the list of traded commodities was more comprehensive.

Moreover, in the 2010 Edition of the NFA, intensities of The Total Primary Energy Supply prior to 1971 have been recalculated, using the change in intensity for those individual countries that do have historical data available as a proxy for the change in global intensity. The algorithm used was thus: for each country missing a complete time series, we took the 3 most closely correlated countries (in terms of % change in the parts of the time series that overlapped) and used the average % change in these to extrapolate back. Traded goods which are reported in units other than mass (e.g. number or volume) are now included in the embodied carbon import and export calculations, since for these items a traded mass is usually provided as a secondary measure.

Land Cover Changes

For European countries, the 2008 Edition of the NFA used the CLC 2000 dataset for areas under various land cover. In the 2009 Edition, CLC data for 1990 has been added, with areas interpolated between 1990 and 2000. For years outside this range, the change in area reported in the FAO data has been used to scale the CLC reported areas. In the 2010 Edition of the NFA, CORINE Land Cover 2006 data was included and the CORINE Land Cover and NFA correspondence revised.

The equivalence factor calculation has been improved slightly. In previous editions, the equivalence factors shifted abruptly between 1991 and 1992, primarily due to a difference in various land cover areas reported by the USSR and those reported by former Soviet countries. To address this, the 1991 USSR areas have been scaled to match the aggregate areas reported by all former Soviet countries in 1992. The percent change in reported USSR areas is then applied to the USSR 1991 estimate to create a consistent time series. In addition, the distribution of GAEZ suitability indices in the USSR was calculated, based on the distributions reported for the former Soviet Republics. This leads to greater inter-annual consistency in the equivalence factors.

The land cover category "Other Wooded Land," included in the 2008 Edition of the NFA as a subcategory of grazing land, has been removed since the 2009 Edition. This category is no longer reported in any available FAO dataset, and in at least some cases it appears to be double counting areas already reported in other FAO land use categories.

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