

A Research Agenda for Improving National Ecological Footprint Accounts

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ABSTRACT Nation-level Ecological Footprint accounts are currently produced for more than 150 nations, with multiple calculations available for some nations. The data sets that result from these national assessments typically serve as the basis for Footprint calculations at smaller scales, including those for regions, cities, businesses, and individuals. Global Footprint Network's National Footprint Accounts, supported and used by more than 70 major organizations worldwide, contain the most widely used national accounting methodology today. The National Footprint Accounts calculations are undergoing continuous improvement as better data becomes available and new methodologies are developed. In this paper, a community of active Ecological Footprint practitioners and users propose key research priorities for improving national Ecological Footprint accounting. For each of the proposed improvements, we briefly review relevant literature, summarize the current state of debate, and suggest approaches for further development. The research agenda will serve as a reference for a large scale, international research program devoted to furthering the development of national Ecological Footprint accounting methodology.

Conference Theme: Ecological Footprint Methodology

Keywords: Ecological Footprint, National Footprint Accounts, Review, Methodology, Research

1 Introduction

The modern Ecological Footprint concept was formally introduced by Mathis Wackernagel and William Rees in the early 1990's (Rees 1992, Wackernagel 1994, Rees 1996, Wackernagel and Rees 1996). Responding to the then-current debates surrounding carrying capacity (e.g., Meadows 1972; Ehrlich 1982; Tiezzi 1984, 1996), Ecological Footprint accounting was designed to represent actual human consumption of biological resources and generation of wastes in terms of appropriated ecosystem area, which can be compared to the biosphere's productive capacity in a given year. Since living renewable resources regenerate using solar energy, a population Ecological Footprint can be said to represent the area continuously required to generate a quantity of photosynthetic biomass energy and material equivalent to the amount used and dissipated by the population's consumption (Rees 2003, 2006, Wackernagel and Galli in press). In focusing only on bioproductive area and on resources presently extracted and wastes presently generated, the method provided a focused assessment of human demand on the biosphere and the biosphere's ability to meet those specific demands (Wackernagel et al 1999a).

Although Ecological Footprint analyses have been performed at scales ranging from single products to the world as a whole, nation-level Ecological Footprint assessments are often regarded as the most complete. National Ecological Footprint accounts are applied directly as a communication and policy tool (e.g., WWF 2006, von Stokar et al 2006), and data extracted from these accounts often serve as a starting point for smaller-scale analyses (e.g., Chambers et al 2000, Lewan and Simmons 2001, Wiedmann et al 2006b). Country-level Footprint assessments have been completed for many nations, with some nations analyzed multiple times under different methods (Wackernagel and Rees 1996, Bicknell et al 1998, Fricker 1998, Simpson et al 2001, van Vuuren and Smeets 2000, Ferng 2001, Haberl et al 2001, Lenzen and Murray 2001, 2003, McDonald and Patterson 2004, Monfreda et al 2004, Bagliani et al 2005, Medved 2006, WWF 2006).

The most widely used methodology for national Footprint accounting today is Global Footprint Network's National Footprint Accounts, developed and maintained by Global Footprint Network and its 75 partner organizations. These reference accounts cover more than 150 nations and extend from 1961 through 2003 (WWF 2006). The ongoing process of improving the quality and accuracy of these accounts is overseen by Global Footprint Network's National Accounts Review Committee, with research contributions solicited from the global community of Footprint researchers (Global Footprint Network 2007a).

This paper contains a summary of open research topics for improving the existing National Footprint Account methods, as suggested by an international group of current Ecological Footprint practitioners and users. Many of these suggested improvements address standing criticisms of current methods from both within and outside this group of authors. A broad range of topics is included here as a reference and starting point for discussion¹.

All of the suggestions for research outlined here are made in recognition of the purposes for which the National Footprint Accounts have been created and maintained. These accounts provide:

¹ The inclusion of any specific research topic should not imply its endorsement by any specific subset of authors.

- A scientifically robust calculation of the demands placed by different nations on the regenerative capacity of the biosphere,
- Basic information on the sources of those demands that is useful for developing policies to live within biophysical limits,
- A consistent method that allows for international comparisons of nations' demands on global regenerative capacity, and
- A core dataset that can be used as the basis of sub-national Ecological Footprint analyses, such as those for provinces, states, businesses, or products.

2 Research Topics

This twenty six research topics described below reflect the major concerns and suggestions of the authors of this paper. Many of these research items respond to published reviews and criticisms of the existing Ecological Footprint methodology. Major reviews of this nature include Van den Bergh and Verbruggen 1999, Chambers 2001, George and Dias 2005, and Schaefer et al 2006. Every attempt has been made to capture published data and methodological criticisms and suggestions from beyond this author group. Omissions reflect only the difficulties of compiling a comprehensive yet readable survey, not any judgment regarding the importance or merits of omitted research on the part of the authors.

Much, though not all, of this discussion assumes a basic familiarity with Ecological Footprint analysis and techniques for National Footprint Accounting. Readers looking for an introduction to this material are encouraged to review Wackernagel and Rees 1996, Bicknell 1998, Wackernagel et al 1999b, Lenzen and Murray 2001, Rees 2001, 2002, Monfreda et al 2004, and Kitzes et al 2007a.

Each research item contains a brief description of the issue under discussion, a summary of the current literature, and notes on the current state of debate. These items are grouped and ordered by common themes, and are not presented in any order of importance or urgency.

2.1 Accuracy of Source Data

The National Footprint Accounts are based on a variety of international and national data sources, including databases from the United Nations Food and Agriculture Organization, the United Nations Statistics Division, and the International Energy Agency (FAOSTAT 2007, UN Comtrade 2007a, IEA 2007). Other data are drawn from published scientific papers, satellite land use surveys, and national and regional databases. Much data is self reported, and metadata describing the methods of data collection, aggregation, and frequency of updates are commonly, though not always, publicly available.

Many researchers, as well as some national governments, have expressed concerns regarding the quality of available source data sets. In the United Arab Emirates, for example, government agencies have expressed their opinion that the frequency of data reporting, the lack of reporting for certain commodities, and methods for measuring population may be significantly biasing the results for that nation (EAD 2006). Systematic distortions in the marine fish catch reported by China may be large enough to affect estimates of the fishing

grounds Footprint of not only that nation but the entire world (Watson and Pauly 2001). Official statistics may not cover “off the books” transactions and may incompletely cover household extraction and consumption that does not enter into markets (e.g., subsistence farming, small-scale fuel wood harvest).

Improvements to the underlying source data for Footprint accounting must address both biased and mis-reported datasets at a national level as well as possible errors and systematic distortions resulting from the translation of national data into standardized international classification systems. One method for evaluating the extent of these inaccuracies is through independent, scientific reviews of the underlying data sets used to calculate each nation’s Ecological Footprint. Agencies within the governments of Switzerland (von Stokar et al 2006), Finland (Väinämö et al 2006), Ireland, Germany (Giljum et al 2007), and Japan have already sponsored complete or partial reviews of this nature.

2.2 Multiple Data Sources

Where possible, Footprint accounts should make efforts to use the most detailed and accurate source data available for national calculations. High resolution data sets are available for many high-income countries, and are often available in a consistent regional format (Schaefer et al 2007). When these more detailed data sets are available, Footprint accounts should provide the option to calculate national Footprints based on these data in addition to internationally available statistics. This could allow for more accurate results as well as providing a second set of data for use in sensitivity analysis (see Section 2.4).

Researchers should exercise caution when comparing calculation results derived from different data sources, as different product lists and classification systems are likely to produce corresponding differences in Footprint estimates. Including products from European national data sets that are excluded from international databases, for example, could inflate national and regional Footprint calculations for Europe.

International statistical agencies are encouraged to publish, and researchers are encouraged to review, the compilers manuals and correspondence tables that are used to convert national statistical classifications to international systems in an effort to correct any errors or distortions.

2.3 Improvement of Key Constants

In addition to data on production and trade flows for each nation, the National Footprint Accounts rely on a number of key constants to translate material extraction and waste emission into units of productive area. These constants include the amount of carbon sequestered per hectare of world-average forest (IPCC 2006), the total sustainable harvest of marine fish, invertebrate, and plant species, (FAO 1971, Pauly 1996), the feed conversion ratios and feed baskets of various livestock (Steinfeld et al 2006), and others.

Key constants, such as the above, that are known to have a large influence on the overall Footprint calculations should be subject to specific additional scientific analysis. Where appropriate, likely ranges for these constants should be applied to generate a range or set of

standard error estimates for Footprint result sets. This list of key constants should be selected by expert opinion coupled with formal sensitivity analysis.

2.4 Sensitivity Analysis

Although many researchers have suggested that the standard error of national Footprint accounting remains fairly high, no major systematic analyses have yet been published to examine and test confidence levels of source data in the National Footprint Accounts (Giljum et al 2007 and Lewis et al 2007 represent perhaps the first). Accounting methods and assumptions should be subject to additional formal analysis and “reality checks” using a range of published data sources.

In addition to purely mathematical simulations from within the existing calculation framework, a broad definition of sensitivity analysis would include investigations of alternative methods that may affect final Footprint results. These might include new techniques for calculating the Footprint embodied in traded goods (Section 2.8), alternate methods for calculating equivalence factors (Section 2.11), or a shift in the basis for calculating the carbon Footprint (Section 2.13). These analyses of alternate methods should be compared to existing methods, with documentation of differences and their significance.

2.5 Detailed Written Documentation

Published methods papers (e.g., Lenzen and Murray 2001, Monfreda et al 2004, Wiedmann et al 2006, Kitzes et al 2007a) are generally the most detailed current guides to understanding the overall framework of national Footprint calculations. Many complexities of the implementation of these calculations, however, remain undocumented in written publications. Widely applied national Footprint calculation methods, such as that of the National Footprint Accounts, should be distributed along with a guidebook explaining the details of the actual account implementation, including the selection of specific data sources, constants, and functions (Schaefer et al 2006).

This documentation should make an effort to describe, and justify where necessary, differences between current calculation methods and previous methods. The past three annual editions of the National Footprint Accounts, for example, have all included revisions to previous methodologies as new data sets and scientific understanding have become available. When annual editions are not directly comparable, guidebooks and release notes should specifically address the rationale and method behind any major changes.

2.6 Measured vs. Calculated Land Use

The current National Footprint Accounts calculate Footprints in units of global hectares by dividing a nation’s total extraction of a product by the world-average yield for that product and multiplying by the appropriate equivalence factor (Monfreda et al 2004). The accounts can also be configured to calculate Footprints in local or national-average hectares for a specific land type, by dividing a nation’s extraction for a product by that nation’s yield for the

product, without the use of equivalence factors. This “calculated area” approach is widely applied (e.g., Monfreda et al 2004, Erb 2004a, WWF 2006).

A second method is “measured area”, which draws area occupied estimates directly from land use and land cover surveys, and often combines these areas with disturbance weightings (e.g., Bicknell et al 1998, Lenzen and Murray 2001). In this method, Footprints are generally measured in actual hectares².

The measured area method gives a more accurate depiction of the physical area occupied within a nation to the extent that uncertainties within land cover surveys, field based or remote, are smaller than uncertainties in production and yield data sets. The calculated area approach, however, inherently addresses partial occupation of areas, while the additional disturbance or intensity multipliers are needed to account for the intensity of use in a measured area approach (Lenzen and Murray 2001, Lenzen and Murray 2003). The basis for disturbance and intensity multipliers continues to be debated, especially as they may show significant geographic variation (e.g., the disturbance caused by grazing in low-productivity arid regions may be of a different magnitude than that caused by grazing in high-productivity regions).

Importantly, neither measured area nor calculated area methods provide specific information about the long term impacts of current practices, but only uncover whether current practices are within or exceed the capacity of the biosphere. A calculated area method, for example, indicates whether a forest is harvested slower or faster than it is growing, but does not indicate whether current harvest practices may have negative impacts in the future (see Section 2.26).

2.7 Local vs. Global Hectares

The National Footprint Accounts are configured by default to report calculation results in global hectares, hectares normalized to have world-average biological productivity in a given year. This normalization is accomplished through the use of world-average yields and equivalence factors which, under the current method, compare the potential productivity of land under different types of ecosystems (see Section 2.11). Results expressed in global hectares answer the research question, “how much of the planet’s regenerative capacity is used by a specific human activity or population?” (Monfreda et al 2004).

Ecological Footprint accounts can also be calculated in local hectares, however, without applying productivity-based normalization. Footprints expressed in local hectares answer the question, “how much bioproductive area is used by a given human activity or population?” (Van Vuuren and Smeets 2000, Lenzen and Murray 2001, Erb 2004a, Wackernagel et al 2004). Local hectare Footprints can be determined either through a measured area approach, where calculations are based on measured land use as reported in national statistics or derived from remote sensing applications, or through a calculated area approach, in which product flows are simply divided by local yields (see Section 2.6).

² Because the measured area approach does not involve a comparison of annual growth to extraction, this method cannot itself show over or under-use of a specific area (e.g., a single hectare of forest could be harvested at levels greater or less than its annual growth, and the measured area approach would assign both of these uses the same Footprint of one hectare). There is no difference between measured and calculated area approaches for cropland, where by definition, the amount of product grown and extracted each year is the same.

For some applications, such as projects focused on local resource management and its temporal dynamics, the use of local yields, and local hectares, may be more appropriate than global hectares (Erb 2004a, Gerbens-Leenes et al 2002, Gerbens-Leenes and Nonhebel 2002, Wiedmann and Lenzen 2007). Other consumption-focused applications where the analyst wishes to make global comparisons may benefit from the use of global hectares. While some researchers maintain that only hectares provide an actual observable measure of demand (e.g., Van den Bergh et al 1999), others maintain that, from a sustainable use perspective, different land cannot be directly compared or summed without applying some form of productivity weighting (e.g., Wackernagel et al 2004).

For example, under a local hectare approach, a nomadic herder ranging seasonally over 10 hectares of low-productivity, arid grassland will have a Footprint far greater than an individual who consumes the products of 5 hectares of the most productive cropland in Switzerland. Whether this is an accurate or a misleading result depends on the research question addressed, as described above, and is highly context specific.

The global hectare approach documents local demand (and supply) in the global context, and is thus particularly useful for comparisons across geographic regions. Local hectare approaches quantify the actual area occupied by the socioeconomic metabolism of a given population and may be able to spatially locate this area demand. Local hectare measurements can be systematically complemented with indicators which estimate the intensity with which land is used, such as the “human appropriation of net primary production” (Vitousek et al. 1986, Haberl et al. 2001, Haberl et al. 2004a, 2004b, Imhoff et al. 2004, Krausmann et al. 2004) or assessments that evaluate changes in ecosystem processes induced by land use (e.g., the effects of land use on biodiversity).

Global hectare estimates should continue to be refined through formal consideration of the basis for equivalence factors (Section 2.11) as well as potential inconsistencies in the use of extraction rates for the calculation of the Footprint of non-primary products (Venetoulis and Talberth 2007). Specifically, Wiedmann and Lenzen (2007) note a discrepancy between the treatment of primary and secondary products under the current global hectare methodology. Since global hectare-based Footprints are determined using world-average yields and equivalence factors, but the efficiencies of secondary production are country specific, global hectare Footprint accounts are not dependent on local land management and resource extraction efficiencies but are dependent on efficiency of secondary production. This can be seen as a methodological inconsistency.

Local hectare methodologies should continue to refine the scientific basis for calculating disturbance weights, investigate the linkages between Footprint and other indicators of land use such as land use intensity, examine the relationship between Footprint and ecosystem functioning, and explore the possibilities provided by spatially explicit Footprint and biocapacity assessments. Reports and assessments using each unit should clearly describe the research question being addressed to aid users in general understanding of the differences between these two methods.

2.8 Trade

Broadly speaking, two methods are described in the existing literature for estimating the Ecological Footprint embodied in traded goods. “Material balance” approaches multiply the reported weights of product flows between nations by Footprint intensities in global hectares, or hectares, per tonne to arrive at an estimate of total global hectares imported or exported (e.g., Monfreda et al 2004). These intensities are derived from ecosystem yields combined with embodied material and energy values usually drawn from LCA product analyses. A material balance type analysis is currently used within the National Footprint Accounts.

An alternative “Input-Output” framework for assessing Footprint trade has also been proposed (Bicknell 1998, Lenzen and Murray 2001, Bagliani et al 2003, Hubacek and Giljum 2003, Turner et al 2007, Wiedmann et al 2007). Input-output based approaches allocate the Ecological Footprint, or any of its underlying component parts, amongst economic sectors, and then to final consumption categories, using direct and indirect monetary or physical flows as described in nation-level supply and use or symmetric input-output tables. By isolating the total value or weight imports and exports by sector, and combining these with Footprint multipliers, total Footprint imports and exports can be calculated. Input-output tables are provided by national statistical offices (e.g., ABS, 2007) or international organizations (e.g., OECD 2006b).

Mathematically, it has been shown that the material balance methodology currently used in the National Footprint Accounts is a special case of a generalized physical input-output formulation (Wiedmann and Lenzen 2007). In practice, however, the limited availability of data sets and necessary simplifications mean that the two methods produce inconsistent results. Most significantly, material flow approaches suffer from truncation errors, or a lack of full coverage of indirect upstream flows (Lenzen 2001a), and may be subject to over and under counting when used in combination due to a lack of standardized boundary setting principles among process-flow LCA studies. Input-output methods suffer from low product resolution and, often, the use of monetary data to proxy for physical flows, among other uncertainties (Lenzen 2001b).

Within a material balance framework, the most important priority will be to locate more robust country-specific embodied energy figures to more accurately capture the carbon embodied in traded goods. Although these data have historically been lacking, increasing global focus on carbon and carbon markets could potentially lead to increasing research in this area. Many newer LCA databases derive their estimates using input-output frameworks, which may lead to convergence between these two methods (Hendrickson et al 1998, Joshi 1999, Treloar et al 2000, Lenzen 2002, Suh and Huppes 2002, Nijdam et al 2005, Heijungs et al 2006, Tukker et al 2006, Weidema et al 2005, Wiedmann et al 2006a).

An input-output based framework may suffer from long time delays between the publication of tables, as well as other documented error types associated with general input-output analysis (Bicknell 1998). Although the use of monetary input output frameworks can help to establish a direct link between economic activities and environmental consequences, questions remain about whether purely monetary tables are appropriate for use in assessing land appropriation (Hubacek and Giljum 2003). Some authors (e.g. Weisz and Duchin 2006) have argued that the best approach for environmentally-related input-output analysis would be the use of hybrid input-output tables comprising both physical and monetary data.

Although in the past, input-output tables have been available only for a subset of nations, newer multi-sector, multi-region input-output analyses could be applied to Ecological

Footprint analysis. The theoretical basis for these models has been discussed, (Turner et al in press, Wiedmann et al 2007), but such an analysis has not yet been completed. The application of such models will need to explicitly consider the production recipe, land and energy use as well as emissions (OECD 2006a).

Monetary input-output based frameworks also may provide the additional benefit of accounting for international trade in services in addition to goods. As many services traded across borders require biological capacity to support but have no physical product associated with them (e.g., insurance, banking, customer service, etc.), trade in these services could only be captured by non-physical accounts. The current omission of trade in services has the potential to bias upward the Footprint of service exporting nations, such as those with large telecommunications sectors, research and development, or knowledge-based industries.

2.9 Producer and Consumer Responsibility

In the determination of the Footprint embodied in traded goods, researchers have questioned whether a portion of the Footprint associated with exported goods should be purposefully retained within the exporting country. This suggestion stems both from the recognition that individuals in the exporting country retains a portion of the economic benefit of the production of that good³ and from methods that divide the total Ecological Footprint between producers (economic entities) and consumers.

This second suggestion reflects a “shared responsibility” framework in which the Footprint of a processed product is divided between all of the various sectors that extract and process a product and its final consumer (Gallego and Lenzen 2005, Lenzen et al 2007)⁴. The current accounts, taking a full consumer responsibility approach, allocate the entire Footprint of a processed product to its country of final consumption. Because under a shared responsibility approach, a portion of the Footprint of a processed product would be retained by the country in which the processing took place, this shift would tend to raise the Footprint of exporting nations, while lowering the Footprint of importing nations.

The main advantage of the shared responsibility approach is that the sum of the Footprint of all producing and consuming entities in the world, for example, would give the total global Footprint. Under the current approach, the sum of all consuming entities alone gives the total global Footprint, while the sum of producers and consumers results in multiple-counting. Arguably, the use of the National Footprint Account in sector or business transformation would be enhanced if this multiple-counting of producers and consumers was avoided.

This approach has the disadvantage of requiring a decision regarding the allocation principle between producing and consuming entities. Proposed allocation principles have been economic (e.g., based on value added) or assumed (e.g., 50-50 consumers and producers), but

³ Any retained Footprint would be in addition to the indirect Footprint effects of increased income, which, to the extent that increased income levels lead to increased consumption of ecosystem products, would be captured in the existing method by a resultant increase in domestic consumption in the exporting country.

⁴ At the national level, the decision of a shared or consumer responsibility framework affects the total Footprint of nations only through its affect on the Footprint of traded goods, since the material balance framework of current accounts only considers the Footprint of processed products when they are traded. Consumer, producer, and shared responsibility frameworks will lead to significantly different allocations of Footprint within a nation, however.

not generally biophysical in nature. Introducing non-biophysical data sets into national Footprint calculations adds an additional level of complexity and brings Footprint accounts farther from their reliance on simple ecological realities. This could make the accounts more difficult to interpret or explain to the general public, who may approach Ecological Footprint accounts assuming a consumer responsibility principle⁵.

2.10 Tourism

Currently, the Footprint of international tourism is allocated to the country in which the tourist is traveling. Since tourism is generally regarded as an export sector of the economy, this represents a methodological inconsistency. As the Footprint of a nation is defined as the demand on regenerative capacity placed by the activities of the residents of that nation, the Footprint of tourist activities should be allocated instead to the home country of the tourist. This inconsistency could prove significant for small nations with well-developed tourism infrastructure.

Although case study analyses have been completed on the Footprint of tourism in various nations and regions (Gössling et al 2002, Hunter 2002, Tiezzi et al 2004, Peeters and Schouten 2006, Hunter and Shaw 2007, Patterson et al 2004, 2007a, 2007b, Bagliani et al in press), no systematic, internationally comparable calculations of the Footprint of tourism, divided by country of tourist residence and location of tourist activities, have been completed to date.

The lack of an international, standardized data set reporting detailed information about tourism and tourist travels remains a major obstacle to officially including such calculations in the National Footprint Accounts. Compiling such a data set manually, nation by nation, would be both time and resource intensive. Given that expenditure data related to tourism is often tracked within monetary input-output tables, these tables may be the best currently available data sets for comprehensive analysis of tourism activities.

2.11 Equivalence Factors

Equivalence factors are used to convert world-average land of a specific type, such as cropland or forest, to global hectares. Global hectares are defined as hectares with world-average biological productivity, or ability to produce useful goods and services for humans⁶. By converting physical hectares into the “common currency” of global hectares based on productivity, comparisons between Footprints and biocapacities of different land types are possible.

⁵ The full consumer responsibility approach can be simply explained to an end consumer: the Ecological Footprint is the sum of all of the areas required to make the products you consume and absorb the wastes you generate. A shared responsibility principle would require additional explanation regarding which portion of the areas are allocated not to the consumer but to producing entities, and the principle on which this allocation is based.

⁶ The consideration of only “useful” products, defined as those that are actually extracted within a given year, reflect the anthropocentric underpinnings of Ecological Footprint analysis. The consideration of only useful products is one major reason why Ecological Footprint and biocapacity analysis show global overshoot, but measures such as human appropriation of NPP do not show 100% or greater than 100% appropriation.

Current equivalence factors in the National Footprint Accounts are based on estimates of achievable crop yields as compared to maximum potential crop yields from the Global Agro-Ecological Zones (GAEZ) assessment (FAO/IIASA 2000)⁷. Alternate approaches include basing equivalence factors on total NPP (Venetoulis and Talberth 2007) or on usable NPP, as defined by the NPP embodied in extractable products from a given land type.

The GAEZ assessment model has the advantage of reflecting land quality using a single measurement unit, crop yields, that is highly relevant to human activities. Total NPP measurements have been criticized for reflecting relative levels of total production rather than those useful for humans. As NPP may also depend heavily on the degree of human management, the use of NPP-based equivalence factors may strongly reflect the current extent and distribution of human intervention (i.e., poor quality land that is intensively managed may be calculated to have a higher equivalence factor than high quality, unmanaged land).

Conversely, equivalence factors based on a form of NPP would be more closely linked to the central unit of ecosystem functioning and would allow closer comparisons between Footprint result sets and other ecological indicators. The use of “usable” NPP as an equivalence factor basis has the potential to combine the benefits of both approaches while taking advantage of the most current remote sensing and ecosystem modeling data sets. Definitions of “usability” will need to be defined carefully, as usability is not an intrinsic function of ecosystems but rather depends on either present human behavior or assumptions about value. Under any approach, GIS models should be strongly considered for their ability to provide better estimates than low-resolution tables and aggregate estimates.

2.12 Nuclear Footprint

A calculation of the amount of land demanded by the generation of nuclear electricity, although not originally included in Footprint methods (Wackernagel and Rees 1996), is now included in the National Footprint Accounts. The “nuclear land Footprint” is calculated as the amount of land that would be required to sequester the emissions of carbon dioxide if the same amount of electricity were generated using fossil fuel energy sources. This method was originally included in Footprint accounts as a placeholder until further research on the actual demand on biocapacity associated with nuclear energy could be assessed.

Increasing scrutiny of this assumption has led to a series of research projects focused on both the theoretical and practical basis of this nuclear Footprint calculation. Many researchers now believe that the Footprint of nuclear land should not be calculated using the fossil fuel equivalent method, as this equivalency does not reflect any measurement of actual demand on the biosphere. One suggestion is that the nuclear Footprint would instead be defined as a type of consumption activity, similar to the Footprint of other activities. Under this method, the Footprint of nuclear electricity would be the amount of Footprint related to the consumption of those products necessary to produce nuclear electricity, such as forest land for creating infrastructure, built land for physical space, carbon sequestration land for carbon

⁷ With the current equivalence factors, productivity is normalized across land types by assigning each land type an average suitability index, which compares the maximum attainable crop yields on that land type with the current maximum theoretical yields for that crop. The ratio of the suitability index for each land type to the average for all land types generates the equivalence factors. “Productivity” within this method is thus defined as an estimate of potential crop production, not common ecological measures such as GPP, NPP, NEP, or NBP.

dioxide emissions (ISA 2006), and perhaps productive land already rendered unproductive by contamination. No additional equivalency-based calculation of “nuclear land” would be included.

Other impacts, such as the potential risk of a future nuclear accident or the Footprint required for future waste disposal, would be reflected in biocapacity and Footprint accounts only when they occurred, consistent with the existing accounting framework (Section 2.25). This method of not including potential future impacts in the core National Footprint Accounts can lead those not familiar with the present-day focus of these accounts to conclude that activities, such as nuclear power, that place small current demands but high expected future demands, are better for the biosphere. In such cases, the use of extended accounts in tandem with the National Footprint Accounts may be the most appropriate means of addressing this mis-interpretation, and this message should be communicated to the appropriate policy makers.

The amount of communication necessary to describe the appropriate use of multiple assessment tools in some decision making, such as the choice between nuclear and fossil fuel electricity, may prove more difficult in short, simple applications intended for the general public. These communication challenges will need to be addressed in tandem with any methodological changes.

2.13 Carbon Footprint

As carbon dioxide represents one of the most significant human demands on the biosphere’s regenerative capacity, many different methods have been developed for calculating the Footprint of carbon dioxide emissions (e.g., Wackernagel and Rees 1996). The National Footprint Accounts currently calculate this Footprint as the amount of forest land that would be necessary to sequester carbon dioxide emissions from fossil fuel combustion through the use of sequestration values for world-average forest, after adjusting for uptake by the oceans (Monfreda et al 2004)⁸. As the carbon Footprint makes up nearly one half of the total global Footprint in recent years under this method (WWF 2006), aggregated national and global Footprint estimates are extremely sensitive to methodological decisions about how to calculate the carbon Footprint.

Alternate proposed methods for measuring the Ecological Footprint of carbon dioxide include calculating:

1. the amount of world-average bioproductive land of all types needed to sequester anthropogenic carbon emissions,
2. changes in the extent and production of bioproductive land under climate change scenarios, with an allocation of a portion of this decrease in productivity to current carbon emissions (Lenzen and Murray 2001),
3. the number of global hectares that would be required to produce a quantity of biofuels equal in energy potential to the fossil fuels being combusted, consistent with a thermodynamic equivalency framework (Wackernagel and Rees 1996),

⁸ This approach has been disputed most commonly (e.g., Wackernagel and Silverstein 2000) on the basis that only relatively young forests fix significant amounts of carbon, and thus land set aside for carbon sequestration will not provide this service indefinitely, but would have to be preserved indefinitely, to be counted as a true carbon sink.

4. the number of global hectares originally needed to produce the living matter embodied in a given quantity of fossil fuel.

The first of these has the advantage of considering land other than forest that is available to sequester carbon, perhaps more accurately reflecting the current state of the biosphere's actual ability to cope with carbon emissions (Venetoulis and Talberth 2007). Conversely, mature ecosystems may have little to no sequestration potential, and as such using actual sequestration values for the biosphere as a whole may more reflect historical overuse (Erb 2004b, Erb et al 2007, Gingrich et al 2007) or carbon fertilization (Schimel et al 2001) than any inherent regenerative capacity for absorbing carbon. Additionally, as the land set aside for sequestration must be permanently reserved, with no option for future extraction of the fixed carbon, a complex assessment of competing land uses would need to be employed (Nonhebel 2004). A final criticism, relevant to both this option and the existing method, is that the calculation of sequestration area runs a high risk of misinterpretation, as it might suggest to the casual user that land sequestration (reforestation) is the solution to carbon emissions (Van den bergh et al 1999).

The second of these has the advantage of reflecting the results of climate change on the biosphere, rather than the amount of productivity required to ensure that these results do not occur. This distinction parallels the avoided damages versus cost of abatement calculations in climate change literature (e.g., Stern 2006). Predictions of future damages are subject to inherent modeling uncertainty, and a systematic and transparent framework must be developed to answer questions regarding discount rates, option value, and other issues inherent in valuing the future. The use of predictive future models would also shift the accounts away from their present and historical focus.

The third option, calculating the area that would have been needed to produce the same energy in biological fuel, has advantages of easy communication, but may more closely measure substitutability than actual demand on the biosphere in a given year (see parallel equivalency discussion for nuclear electricity, Section 2.12). Because the chemical energy and carbon content of biofuels are closely related, results from these calculations for wood fuel, one of the previously implemented methods (Wackernagel and Rees 1996, Monfreda et al 2004), tend to resemble the results of sequestration analyses when the basis for comparison is thermal energy⁹.

The final option takes a capital maintenance perspective, and indicates how much bioproductive land would be necessary to preserve fossil fuel stocks at current levels. This approach has been examined the least of these four possibilities, as the Footprint has historically been more concerned with demands on the present day biosphere than on maintaining stocks of non-renewable materials, such as fossil fuels, outside of the living biosphere. This calculation may also prove extremely difficult in the aggregate, given the location-specific and variable conditions under which fossil fuels have formed.

⁹ The thermal energy produced by a hectare of wood fuel is similar to the thermal energy produced by an amount of fossil fuel that produces carbon emissions that can be sequestered by one hectare of forest. If the basis for comparison was instead a liquid fuel that required additional processing and losses, the biomass substitution method would give a far larger Footprint than the current forest sequestration method.

2.14 Other Greenhouse Gases

Although the National Footprint Accounts now include emissions of carbon dioxide using the carbon sequestration method, the emissions of other greenhouse gases, such as methane, nitrous oxide, fluorocarbons, and sulfur hexafluoride, are not calculated to have an additional Footprint beyond the energy required for their creation.

The most common suggested method for including these gases in Footprint accounts is through the use of global warming potentials (Lenzen and Murray 2001, Barrett et al 2002, Holden and Hoyer 2005, Dias de Oliveira et al 2005), which reflect the radiative forcing and atmospheric lifetime of each gas (IPCC 2001). These potentials convert each gas into its carbon dioxide equivalent based on its ability to absorb and re-release radiation in the atmosphere over its projected atmospheric lifetime. Current emission levels of these other greenhouse gases have a warming potential equal to as much as 30% of present carbon dioxide emissions (IEA 2007).

A second method could involve calculations of the atmospheric lifetime and biospheric sequestration pathways for these other gases. Methane, for example, could be analyzed according to its atmospheric lifetime and degradation pathway to carbon dioxide (Walsh 2007), or according to the biosphere's specific waste absorption mechanisms for this gas.

The global warming potential method has the advantage of being consistent with increasing global concerns about climate change, and can be interpreted as indicating the amount of additional carbon dioxide that would need to be sequestered to balance the equivalent of other greenhouse gas emissions. Conversely, the warming potential of a greenhouse gas is arguably unrelated to the biosphere's regenerative capacity for these materials. A global warming potential method will become more difficult to justify as these other gases begin to form a larger, non-marginal fraction of total warming potential.

While the second method is consistent with current sequestration-based methods for calculating the Footprint of carbon dioxide, the potential for the biosphere to sequester other greenhouse gases may be difficult to measure or undefined in the cases of some synthetic gases. These synthetic chemicals should arguably be left out of Footprint accounts, similar to other toxic pollutants (Section 2.22). If, however, these chemicals undergo physio-chemical transformations that convert them into materials that the biosphere can absorb (e.g., methane conversion to carbon dioxide in the atmosphere), then the Footprint of these decay products could more readily be included. Either method will need to find consistent data sources that report emissions of other greenhouse gases in annual time series, which may be difficult to locate (e.g., IEA 2007).

2.15 Emissions from Land Use Change

Globally, carbon dioxide emissions from land use change may be as large as 30% of carbon dioxide emissions from fossil fuel combustion (IPCC 2001). Because of difficulties both in measurement and in allocation to human consumption activities, these emissions are not included in current accounts. Estimates of carbon emissions from land use change could be drawn from IPCC estimates (e.g., Lenzen and Murray 2001, 2003), although these provide only decadal resolution and have not been updated since the 1980's, or taken from partial

time series estimates from IEA (IEA 2007). IPCC accounting guidelines (IPCC 2006) could also be used to create estimates of emissions from land use change, although this process may be difficult and data intensive.

The allocation of these land use change emissions presents an additional difficulty. The geographical distribution of emissions may be difficult to obtain, and questions remain as to how the emissions should be allocated to final consumption of products. One suggested option would be to include the Footprint of these emissions as a “tax” on consumption of livestock products or on oil crops, although the multitude of drivers behind land use change might make the allocation to any specific product impossible. A more rigorous analysis would quantify the drivers of land use change emissions, and allocate their associated Footprint accordingly. If a consumption-based approach is not possible, the emissions could be allocated purely on a production-based distribution, where available (e.g., allocated to the country of their origin, with no trading), or allocated to the world as a whole but not to any specific country.

Emissions of other greenhouse gases, especially methane, can result from land conversions and changes in wetland and tundra. Both the measurement and the allocation of these emissions may prove even more difficult than carbon dioxide, especially in cases where the emissions may not be directly attributable to any specific action (e.g., the release of methane from tundra as a positive feedback from an already warming climate). Methods for allocating these indirect emissions, especially when they have the potential to occur in the future, are not clear and not currently counted in the National Footprint Accounts.

2.16 Fisheries Yields

All marine Footprint accounts to date (Monfreda et al 2004, Talberth et al 2007) are calculated by dividing the amount of primary production consumed by an aquatic species over its lifetime by an estimate of the harvestable primary production per hectare of marine area. This harvestable primary production estimate is based on a global estimate of sustainable aquatic species production (FAO 1971), converted into primary production equivalents, and divided by the total available marine area.

Estimates of sustainable aquatic harvest suffer from a number of data limitations and errors in estimation (Pauly 1996), and estimates of actual landings in a given year may be subject to reporting bias (Watson and Pauly 2001). Methods for including bycatch are based on single year estimates (FAO 1971) rather than on time series observations. All of these issues weaken calculations of the fisheries Footprint and biocapacity under current accounting methods.

Most significantly, however, calculations of Footprint and biocapacity for fisheries based only on primary production requirements and a single estimate of sustainable yield ignore the importance of availability and quality of fishing stocks in determining actual regenerative capacity in a given year. Treating the availability of primary production as the only determinant of marine fisheries production might be compared to considering the availability of atmospheric carbon dioxide to be the only determinant of timber growth in forests. The current very small estimate of overshoot in global marine fisheries accounts may be due to exactly this problem, as the accounts are insensitive to any declining quality and yearly sustainable yield of fisheries over time.

A significant improvement to fisheries Footprints would be to calculate the yields for fisheries based on stock quality information for all, or at minimum the most significant, fish species. Data on the quality and reproduction rates of specific fisheries may be extremely difficult to locate, and difficult to compile. Even simple models, however, may represent a theoretical and practical improvement over current methods. These models should make a point of addressing the potential influence and importance to fisheries biocapacity of specific spawning grounds, an issue which has not yet been addressed by fisheries accounts.

2.17 Cropland Yields

For all major land types except for cropland, the yield (product per area) used to calculate the Ecological Footprint is the amount of material produced by that given land type. The yield for calculating the Footprint of one tonne of timber, for example, is equal to forest growth per hectare, not forest harvest per hectare, which may be greater than or less than the actual growth in a given year. When a harvest yield exceeds a growth yield, a specific area enters overshoot.

As a human-created land type, however, cropland has yields of harvest equal to yields of growth by definition. As such, it is not possible with current accounts to show overshoot for the cropland land type. This lack of overshoot has been explained and interpreted as reflecting the “conservative” assumption of Ecological Footprint accounts (Wackernagel and Rees 1996). The energy-intensive inputs required to maintain current yields (e.g., fossil fuels needed for tractors, fertilizers, or pesticides) are considered in aggregate Footprint accounts, but this often large carbon Footprint does not contribute to overshoot in cropland itself.

This lack of overshoot can be interpreted as implied sustainability of cropland, even though intensive agriculture causes other environmental impacts that are arguably not sustainable, such as nutrient leaching, contamination of groundwater and other resources, and soil erosion (Oldeman et al., 1990, Haberl 2006). These additional impacts could be incorporated into extended or satellite accounts to be used alongside core Footprint accounts for multi-criteria decision making (see Sections 2.22), and better communication strategies can be designed to interpret the low Footprint values which may be calculated for intensive agricultural systems.

2.18 Built-up Land

The National Footprint Accounts now include both an Ecological Footprint and biocapacity estimate for built-up land, or land under human infrastructure, calculated by assuming that built infrastructure occupies formerly productive cropland (Wackernagel and Rees 1996). While this assumption was developed for use in temperate countries, where this calculation may hold reasonably true, it is clearly violated elsewhere. In tropical countries, for example, infrastructure often occupies previously forested areas, and in the Middle East and Central Asia, built infrastructure almost certainly occupies formerly arid non-productive land and hence should have no associated biocapacity (EAD 2006). Even in temperate countries, the cropland replaced by built-up land was likely formerly forested, and thus the appropriate land type to use involves a selection of a baseline year for comparison.

Because cropland is the most productive of all land types according to current equivalence factor calculations, the assumption that built space occupies cropland can create a counter-intuitive result when the infrastructure replaces other land types. In this instance, the estimated biocapacity of the nation will actually increase, even though the land itself is degraded (Wackernagel et al 2004). The effect of this overestimate will be small for most nations, however, as built-up land is not a significant portion of most national Footprints (WWF 2006).

These calculations can be made more accurate by estimating more precisely what land type was replaced by built infrastructure. These data can be modeled based on remotely sensed data sets, such as the GLC, GLOBCOVER, or CORINE (JRC 2000, GOF-C-GOLD 2007, LEAC 2007). Global NPP data sets could be used to calculate the actual biological production of areas under infrastructure (from gardens and parks, for example), and this production level could also be used as the basis for biocapacity and Footprint calculations for built-land (Venetoulis and Talberth 2007).

Alternately, it has been suggested that built-up land should be removed entirely from biocapacity and Footprint estimates. Assuming that built land is no longer biologically productive, this land should arguably be excluded from Footprint and biocapacity accounts, which measure demand on and supply of bioproductive land, respectively.

It may be argued, however, that built infrastructure should be treated as a type of occupation of bioproductive land rather than a change in the land type itself, in which case built land should remain in Footprint accounts as demand on bioproductive land and in biocapacity accounts as available, but occupied, bioproductive land. Under this logic, however, aggregated accounts will show no change in biocapacity as previously harvested cropland is covered with infrastructure.

2.19 Additional Land Types

The land categories used in National Footprint Accounts have evolved since their creation, from an initial suite of six land and land use categories (fossil energy use land, degraded land, gardens, crop land, pasture, and forest) to a current list of seven categories (carbon sequestration land, nuclear energy land, built-up land, crop land, grazing land, forest, and fishing grounds) (Wackernagel and Rees 1996, WWF 2006). Since their inception, the accounts have excluded several land types that do not provide significant amounts of concentrated resources for human extraction or waste absorption services, including wetlands, tundra, and deserts.

The distinction between what land types are considered bioproductive and not bioproductive has been criticized as not clearly demarcated and based on subjective judgment (Venetoulis and Talberth 2007). A response could be to expand the coverage of the National Footprint Accounts to include additional land types that provide other types of services to humans, such as wetlands, or to all land types on the planet. At the local level, at least one preliminary study (Bagliani et al 2004) has focused attention on calculating the biocapacity of lagoons and other wetlands, finding that the biocapacity of the lagoon under analysis may be higher on a per hectare basis than open sea. The complexity of wetland and estuary systems may create significant analytical difficulties in choosing and measuring appropriate levels of biomass production and waste absorption services.

Although at a global level, additional ecosystems, such as wetlands, characterized by high productivity but low coverage may not be significant, their contribution to biocapacity may be important at national or sub-national scales. Other ecosystems characterized by low productivity but high coverage, such as tundra, may prove similarly insignificant at local scales but relevant at the scale of the entire biosphere.

2.20 Constant Yield Calculations

Calculating and interpreting Ecological Footprint and biocapacity accounts in time series present additional challenges beyond those encountered in single year analyses (Haberl et al 2001, Erb 2004a, Wackernagel et al 2004b). Because yield values change over time, a single hectare does not necessarily produce the same amount of goods or services each year. Time trends calculated using different yields each year, such as trends expressed in global hectares, thus reflect changes in both total consumption and in yield.

These two factors can be difficult to distinguish under annual yield methods. At a global level, for example, both average material consumption and average yields have increased over the past forty years. Recent analyses suggest that a global hectare in 2003 yielded at least 15% more material than a global hectare in 1961 (Kitzes et al 2007).

An alternate method that could isolate changes in total consumption would be to calculate time series in Footprint and biocapacity using yields for a single reference year. Under this method, time trends will reflect changes in absolute consumption and material extraction (Ferguson 1999, Haberl et al 2001, Wackernagel et al 2004, Kitzes et al in press). Results within any given year other than the base year, however, could be difficult to interpret or communicate. The choice of constant or variable yields should be made on a case by case basis, and, as variable yields are the current norm, applications using constant yields should state this choice clearly. The accounts should provide users with the option of using either constant or annually varying yields.

2.21 Water Use

Although freshwater is a natural resource cycled through the biosphere, and related to many of the biosphere's critical goods and services, it is not itself a creation of the biosphere. Similar to other nutrients, the water is an enabler of bioproductivity (e.g., photosynthesis), but largely not a product of ecosystems. As a result, the Footprint of a given quantity of water cannot be calculated with yield values in the same manner as a quantity of crop or wood product. When values for a "water footprint" are reported, these generally refer to either a measurement of total liters of water consumed, not any measure of land area (e.g., Hoekstra 2007), or a measurement of the Footprint required for a utility to provide a supply of water (Lenzen et al 2003).

The indirect influence of water availability can also be seen through its control on ecosystem yield. Methods for allocating an estimate of the lost yields associated with water use for non-bioproductive purposes has been suggested, but no estimate of this type has yet been completed. As the relationship between freshwater and biological capacity is highly site

specific, this analysis would need to be completed at a regional or local scale on a case-by-case basis.

Other methods for calculating the Footprint of water use could be based on the area of catchments or recharge zone needed to supply a given quantity of water (e.g., Luck et al 2001), although such methods will need to address the potential for double counting with other uses of productive land. Currently, where an application requires that demand on water be tracked directly, water use accounts are often presented in tandem with Footprint assessments (e.g., WWF 2006). Future research into this area should recognize and build on the new United Nations SEEA water accounts (SEEAW).

2.22 Persistent Pollutants

Under current methods and frameworks, toxic materials for which the biosphere has no regenerative capacity for absorption are assigned Footprints associated with the amount of biological capacity required to create them (e.g., energy for processing, area for mining, etc.). There is no Footprint directly assigned to these materials based on the amount of area required to re-absorb them, however, as this area would be undefined or infinite. The total impacts on bioproductive land from materials for which the biosphere has no regenerative capacity are thus not fully reflected in Ecological Footprint accounts. Similar to the use of freshwater, however, any damages to productive ecosystems that result from the release of toxic materials are captured indirectly through decreases in biocapacity, if and when they occur.

Similar to water use, methods for allocating this lost biocapacity to the materials that cause its loss could be developed. Other research could pursue methods for extending the theory of Footprint accounting to include physical cycles (e.g., geochemical processes that can remove pollutants from soils) in addition to biological cycles. In the interim, extended systems of accounts could be developed to measure the 'Ecological Fingerprint' of these materials. As long as these materials remain outside the core National Footprint Accounts, decisions regarding their use or potential use should be evaluated using both information from Ecological Footprint analyses and other sets of indicators.

2.23 Biodiversity

When calculating a nation's ecological reserve or deficit, or local and global overshoot, the National Footprint Accounts do not specifically reduce the amount of available biocapacity to account for the needs of wild species. While quantitative set-asides of biocapacity based on an estimated percentage of land necessary for preserving biodiversity have been used in the past and continue to be suggested (Talberth and Venetoulis 2007), the historical position of the accounts has been to report only on total availability of capacity and demand and allow other decision making tools to address the desirability of leaving a certain amount of capacity aside for wild species. A more measurable criterion for calculating biocapacity available for other species, which has not been completed, may be to estimate the biocapacity currently set-aside in protected areas.

The use of the Ecological Footprint in biodiversity discussions today is largely centered on its ability to measure consumption of biological resources and generation of wastes, both of

which can be viewed as large-scale, indirect drivers of biodiversity loss. In this way, Ecological Footprint accounts have been cited as useful for setting policies to halt or reverse declines in biodiversity (CBD SBSTTA 2005).

When Ecological Footprint analyses are used for smaller scale management decisions, however, these accounts might appear to suggest that increasing the yields of managed ecosystems can be used as a method for decreasing overshoot or a nation's ecological deficit (WWF 2006)¹⁰. To the extent that increasing intensification can lead to declining biodiversity, a narrow focus on reducing overshoot can actually lead to biodiversity loss, rather than preservation (Lenzen et al 2007). Local hectare calculation approaches, which are compatible with other land use intensity indicators, may be able to partially address this concern by distinguishing between the different land types, and specific geographical land areas, demanded for consumption (Section 2.7)

Disturbance-based Ecological Footprint methods have been suggested to address this issue, as increasing disturbance and biodiversity loss may be closely correlated (Lenzen and Murray 2001). Under current accounting methods, the Ecological Footprint should be used for small scale management with other indicators measuring important issues of concern, such as biodiversity loss, to prevent counter-productive decision making (e.g., a policy may be evaluated for its ability to decrease ecological deficit and protect biodiversity using two different assessment tools). In the future, other research into linkages between human activities and biodiversity, such as those related to man-made climate change (e.g. Ohlemüller et al 2006) or human appropriation of net primary productivity (Haberl et al 2004a, 2005) could also be evaluated for its relation to Ecological Footprint calculations and the potential for its inclusion into Footprint accounting methods.

2.24 Multiple Land Uses

Under present accounting methods, land and sea areas serve only a single, mutually-exclusive purpose. The current National Footprint Accounts, for example, allow a single hectare of forest to be used either for timber production, or for carbon sequestration, but not for both simultaneously, as counting both services would create double counting (Venetoulis and Talberth 2007).

The consideration of only a single function per unit of area accurately reflects the mutually exclusive provisioning services and carbon dioxide absorption (MEA 2005) that the accounts are designed to include. This decision prevents the core accounts, however, from considering other ecosystem services, such water catchment or biodiversity services in a forest, that are not mutually exclusive with material production and waste absorption.

To avoid double counting, these other land uses can be assigned an Ecological Footprint in extended Footprint accounts that are not added to the core accounts, since doing so would create double counting. These other services could be measured in either non-additive global hectares (see Section 2.21) or in entirely different units and used alongside Footprint analysis in decision making.

¹⁰ In some cases, the increased Footprint of inputs may partially, or entirely, offset the gains in biocapacity.

2.25 Future Footprints and Biocapacity Loss

One of the most potentially significant considerations not included in the current core National Footprint Accounts are activities that affect future Footprint or biocapacity. Because the accounts are purely historical in nature, capturing past demands on biological capacity and comparing these demands to available capacity in any given year, they cannot capture activities occurring today that will likely cause demands to be placed on ecosystems or will destroy ecosystem capacity in future years¹¹.

Nuclear electricity generation, for example, may place relatively little demand in the present for waste storage and disposal, but future generations will be forced into a certain level of demand to store the wastes generated today. Arguably, this future demand should be allocated to the activities today which are responsible for that demand. Assuming current technology and no discount rate, the net present Footprint of nuclear electricity may be at least an order of magnitude greater than the Footprint of current fossil fuel electricity (Wada 2006), although this calculation is heavily dependent on the assumed time frame for which the waste must be stored. This type of extension to Ecological Footprint accounts could be a critical input into any decision making involving activities that will cause future Footprint expenditures.

Similarly, a decrease in the ability of the biosphere to produce biological resources in the future may be due to present day consumption activities. In the case of the release of persistent, long-lived toxics, for example, the future biocapacity loss associated with these materials is not currently allocated to the present day activities that cause their release. Similar to activities with associated future Footprints, this loss of biocapacity arguably should be allocated to present day activities.

Even when these future losses might be taken into account, the impact horizons associated with different present day demands presents an additional challenge (Lenzen et al 2004). For example, in current accounts, the Footprint associated with the extraction of timber and the absorption of carbon dioxide, both of which place demands on forest, are both calculated using the same yield and productivity factors. This method does not consider that an over-harvested forest may recover within decades from an initial disturbance, but over-emissions of carbon dioxide which are not sequestered will have ecosystem effects for centuries. Because of these different temporal profiles, reducing overshoot early in long-lived components, such as greenhouse gases, will result in less future losses of biocapacity than reducing overshoot in short-lived components. In a static, snapshot-like, non-cumulative approach, these different profiles are not distinguished. Further research into this topic can be informed by analogous discussions in the climate change arena (Rosa and Schaeffer 1995; Rosa and Ribeiro 2001; Rosa et al 2004).

The allocation of Footprint and biocapacity across time, as well as space, will be extremely sensitive to assumptions about future technology and management systems. Such predictive modeling may lie outside the scope of current accounts, which are focused on past and present demands only, but can be an extremely important extension of the core accounting

¹¹ This historical focus is perhaps the most significant difference between current Ecological Footprint analysis and carrying capacity modeling, which attempts to predict how many humans could be supported at any given time.

system. Such analysis will be difficult to conduct, however, and will rely on heavily debated assumptions about future technology, preferences, and appropriate discount rates.

2.26 Policy Linkages and Institutional Context

The utility and application of the National Footprint Accounts are increased to the extent that they can interface well with other existing policy assessment tools. Continued research and refinements should recognize that the Ecological Footprint does not exist “in a vacuum,” but is instead one of a suite of indicators and assessment tools that address different components of the sustainability challenge. Any single indicator can only address a single question, and an integrated approach with multiple criteria can better cover the entire range of concerns relevant for decision making.

One of the most critical needs for the National Footprint Accounts is for their results and assumptions to be made consistent with mainstream economic and environmental accounting. This will allow Footprint calculations to use the best available data as inputs, produce the most consistent and applicable results, and clarify the institutional role of national statistical offices and environmental agencies in this research agenda.

In this regard, Footprint accounting as currently practiced should be understood as a mixture of positive accounting, involving pure measurement of observable variables, and conceptual modeling, where these observations are processed through a series of assumptions to arrive at an additional conclusion. In Footprint accounts, land cover and harvest data reported in physical quantities are an example of the former, while the conversion to global hectares represents the latter. As statistical offices are formally charged with the former positive accounting, with other researchers and analysts involved in the latter, the Footprint must recognize the complementary roles of these two parties and what they can each contribute to these research topics.

A first specific step will be to design national Footprint accounts to be more compatible with other existing standards for economic and environmental accounts. Researchers and analysts involved in Footprint accounting should make additional efforts to understand and harmonize their approaches with existing standards, such as the System of National Accounts, the System of Environmental and Economic Accounting (United Nations et al 2003), the European Strategy for Environmental Accounting, spatial and remote sensing databases, existing ecosystem and natural capital accounting frameworks, and greenhouse gas and carbon reporting conventions. To begin this process, the accounts should move quickly to adopt standard product codes that are identical to or derived from standard product classification systems such as HS2002 or SITC rev.3 (UN Comtrade 2007b).

Additionally, specific efforts should be directed towards investigating how the Ecological Footprint can contribute to existing policy agenda and discussions. Consistent, standardized methods should be developed for the use of the Footprint as a reporting tool, and linkages to global and regional policies, directives, and strategies investigated. Further evaluating and determining where these linkages exist will be critical to the Footprint’s adoption as a serious policy tool.

Finally, in recognition of policy makers’ needs for integrated approaches and indicators, further research should focus on how the Ecological Footprint accounts support and can be

supported by other related indicators, such as Human Appropriation of Net Primary Productivity. This need has been recognized by the European Directorate General of the Environment (DG Environment 2007), as well as many others within government communities, and research is already beginning into these areas (SERI et al 2006).

3 Conclusion

The twenty six topics above represent an inclusive list of both ongoing and proposed research into the methods, data sources, and policy uses of the National Footprint Accounts. A number of observations emerge when considering this list as a whole:

- Many of the changes suggested by critiques of Footprint methodology, or research intended to respond to such critiques, are acknowledged as valid and important by the Footprint research community. The lack of rapid implementation of new extensions and suggestions is most often constrained by a lack of available dedicated personnel and financial resources rather than a lack of understanding or willingness to critically consider current Ecological Footprint accounting practices. This situation is not unique, and has been faced by many if not all indicators during their development process.
- The specific research question of Ecological Footprint accounting, as well as current data limitations, prevent the National Footprint Accounts from including every consideration relevant to sustainability and decision making. For issues where the National Footprint Accounts do not directly apply today, such as nuclear electricity, biodiversity conservation, and freshwater usage, extended Footprint accounts or satellite accounts of a different nature need to be included to arrive at optimal decisions.
- At a macro level, the conservative assumptions of the current model suggest that further research is unlikely to significantly change the most general core messages drawn from Ecological Footprint analysis: the world as a whole is operating in a state of overshoot, which is continuing to increase, with residents of high-income nations demanding more productive capacity than low-income nations.
- The ongoing development of the National Footprint Accounts must proceed with the recognition that the accounts are not purely an academic exercise and already in use. Changes that increase the scientific robustness of the underlying methodology must be made carefully, and accompanied by appropriate documentation, in order to keep the results of the accounts useful and relevant for those currently using these data sets in practice. This will require a careful balance between ensuring both the historical continuity and stability and the improving scientific robustness of these accounts.
- Policy makers need baskets of indicators that cover a broad range of sustainability issues, and no single indicator can be expected to meet every decision making need. Research into ways to use Ecological Footprint accounts in multi-criteria, integrated assessments will be critical to the Footprint's adoption by the broad policy community.

Major stakeholders and researchers clearly recognize the need for further development of all indicators for tracking sustainability. The Ecological Footprint is not an exception. The twenty six research items listed here will support both the future scientific development and the policy application of the Ecological Footprint methods and data.

Organizations such as the European Commission, through its overall efforts to develop indicators in efficiency and productivity in the use of natural resources, WWF international, through its continued promotion of the idea of “One Planet Living”, and academic researchers around the world have supported, and continue to support the development of national Ecological Footprint accounts. Through continued research and development, the strength and relevance of these accounts should continue to grow, supporting decision makers throughout the world who are in need of tools to measure progress toward creating a sustainable society.

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