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The real wealth of nations: Mapping and monetizing the human ecological footprint

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ABSTRACT

The earth provides myriad ecosystem services or 'benefits' that enable and enhance human existence. Humanity, in turn, imposes myriad environmental impacts or 'costs' on the earth. We explore the idea of mapping these 'costs' and 'benefits' using proxy measures. We set the total value of the world's ecosystem services to be equal to the total cost of anthropogenic environmental impacts at fifty trillion dollars (roughly the global GDP in the year 2000). A global representation of ecosystem service value is mapped at 1 km^2 resolution using Net Primary Productivity (NPP) as a proxy measure of ecosystem service value ('benefit'). A similar global representation of environmental impact is mapped using pavement (i.e., anthropogenically created impervious surface area or ISA) as a proxy measure of 'cost'. Subtracting the 50 trillion mapped onto ISA from the 50 trillion mapped onto NPP produces a 1 km^2 resolution map of those areas where: (1) human imposed costs exceed naturally supplied benefits, resulting in an ecological deficit, (2) human costs balance with environmental benefits and (3) environmental benefits exceed human costs, resulting in an ecological surplus. Mapping this ecological balance produces a spatially explicit and monetized representation of ecological sustainability that can be aggregated to national, sub-national, and regional levels. Aggregations of this map at the national level are compared with other national measures of biophysical sustainability such as the Global Footprint Network's 'Eco-Deficit'. An additional benefit of this approach is that the national values derived from this difference map suggest a starting point for discussions of the dollar values and costs of both under and over consumption of ecosystem services on the part of the nations of the world.

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1. Introduction

The idea of 'carrying capacity' is a fundamental ecological indicator of bio-physical sustainability for the human race. Following the publication of Aldo Leopold's '*A Sand County Almanac*' in 1949, Rachel Carson's '*Silent Spring*' in 1962, and Paul and Anne Ehrlich's '*The Population Bomb*' in 1968, the early 1970s were a time of rapidly expanding consciousness of issues associated with environmental degradation and human responsibility for those impacts on the environment. In 1969 the Cuyahoga river in Cleveland Ohio actually caught on fire and there was a significant oil spill in the Santa Barbara Channel. These events likely contributed to precipitating the first 'Earth Day' celebration in 1970. However, oil spills and rivers catching on fire are perhaps not the preferred kind 'ecological indicator'.

Approximately one year after the first 'Earth Day' celebration, Paul Ehrlich and John Holdren published an important conceptual paper titled: *Impact of Population Growth*. This paper postulated an oft-cited equation: $I = P^*A^*T$ (where '*I*' is Impact, '*P*' is Population, '*A*' is Affluence, and '*T*' is Technology (Holdren and Ehrlich, 1974). Questions about human impact on the environment remain with us today and are perhaps even more pressing in light of global climate change, peak oil, and the rapid loss of biodiversity. These questions are often framed within the broader context of "Sustainability". In a strictly bio-physical sense, 'ecologiccal sustainability' is perhaps a more palatable way of expressing the idea of 'Carrying Capacity'.

Debates regarding the validity of the concept of carrying capacity are highly contested and ongoing (Sayre, 2008). Contemporary definitions of human carrying capacity were adapted from ideas about how many cattle a given area of rangeland could support and now include additional variables: '*...the population of humans that can be sustained by a given ecosystem at a given level of consumption, with a given technology*' (Daly and Farley, 2004). It is now generally accepted that variation in areas of technology, ecosystems, and consumption complicate attempts at steady-state equilibrium estimates of carrying capacity for humans (Cliggett, 2001). While the idea of a global 'carrying capacity' for humans

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may be a taboo idea in particular (Hardin, 1978), ideas such as 'sustainable development' (United Nations, 1987) and 'ecological footprint' (Wackernagel and Rees, 1996) have been increasingly incorporated into public discourse. These ideas of 'sustainability' and 'ecological footprint' implicitly contain contemporary ideas of carrying capacity that incorporate some of the complexities of varying ecological environments, technologies, and consumption patterns.

This paper presents a simple spatially explicit measure of ecological sustainability (or carrying capacity if you will) that involves the use of two proxy measures: (1) Anthropogenic Impervious Surface Area (ISA), and (2) Net Primary Productivity (NPP). ISA is used as a measure of human 'demand' on the planet and NPP is used as a measure of 'supply' provided by the planet. ISA are those land surfaces that have been converted by human action to impervious surfaces (e.g. paved streets and highways, parking lots, rooftops, sidewalks, etc.).We use ISA as a spatially explicit model of human impact or 'demand' in the spirit of the $I = P^*A^*T$ model proposed by Ehrlich and Holdren in 1971. We use NPP as a spatially explicit proxy measure of the earth's recurring or renewable natural endowment. We use NPP as a simplified proxy measure of the earth's ecosystem services (de Groot et al., 2002).

The total dollar value of the world's ecosystem services and natural capital has been estimated to be over 50 trillion dollars per year (Costanza et al., 1997). We oversimplify these two models of 'supply' and 'demand' and set them equal to one another globally at a value of $50 trillion (roughly the global Gross Domestic Product (GDP) in the year 2000). The title of this paper pokes a little fun at Adam Smith's seminal and brilliant work (Smith, 1776) because we believe ecosystem services represent a market failure that rivals the global economy in sheer magnitude. Ecosystem services are associated with market failures because ecosystem services are in many cases public goods in and of themselves, are affected by both positive and negative externalities, and have problems associated with unclear property rights definitions. Ecosystem services and natural capital are often overlooked or ignored despite their critical importance to the sustainable functioning of the Earth (Daily, 1997). Costanza et al. (1997) took a careful look at the total global value of ecosystem services and natural capital and noted that "*because ecosystem services are not fully captured in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions*." Given the critical role ecosystem services play in the quality of human life, it is essential that we have methods for considering natural capital in our policy decisions.

Incorporating ecosystem service values into measures of sustainability is challenging for several reasons. One attempt at making a spatially explicit map of sustainability involved applying a simple benefits transfer model to the International Geosphere Biosphere Program's (IGBP) global land cover database to produce a global map of ecosystem service. Sutton and Costanza, 2002 used nighttime satellite imagery and the IGBP land cover data to make global estimates of both Gross Domestic Product (GDP) and Ecosystem Service Product (ESP), allowing for comparison of these two values. They also calculated percentages of national economies derived from ecosystem services and found this value to correlate with Ecological Deficits as defined by Wackernagel and Rees, 1996. Despite these findings there are problems with the simple application of benefits transfer models because spatial context is very important to the valuation of many ecosystem services. Other research on ecosystem service valuation has explored complexities associated with problems that spatial context presents with respect to simple benefits transfer approaches (i.e. the economic value of the erosion control services provided by a boreal forest in location A near a reservoir are likely not the same as those provided in location B far from any built infrastructure). For example, the storm protection services provided by coastal wetlands are a function of the spatial context of storm frequency, built infrastructure, and other nearby wetlands (Costanza et al., 2008). Estimation of the dollar value of ecosystem services is a daunting task for numerous reasons including problems of spatial context, contingent valuation, and sins of omission. Making spatially explicit estimates of the sum of all ecosystem service values is also difficult because some benefits (e.g. carbon sequestration) are not spatially localized whereas other benefits are (e.g. storm protection services). Consequently, the approach we take to producing a map of the dollar value of the earth's recurring natural endowment (i.e. ecosystem services) is simply a map of NPP.

NPP is a fundamental measure of the recurring energy capture services provided by the earth's ecosystems. Imhoff et al., 2004 developed a global map of Human Appropriation of Net Primary Productivity (HANPP). One goal of this map was to identify areas suffering from severe human impact, since "*changing patterns of HANPP will have important consequences for human welfare and global biodiversity*" (Imhoff et al., 2004). They found that globally, humans appropriate about 20% of terrestrial NPP. However, this appropriation of NPP varies significantly around the world. Areas including Western Europe and South Central Asia consume more than 70% of the local NPP while areas including South America use about 6% of their local NPP. Ultimately, "*spatially explicit measures of HANPP [. . .] will help to illuminate current human impacts on the biosphere, monitor changes in these impacts over time and explore the potential of various policies for alleviating them*" (Imhoff et al., 2004). The approach we present here draws from this work on HANPP by placing a dollar value on the NPP itself and presenting a broader spatially explicit model for human impact (monetized anthropogenic ISA).

The goal of this research is to present a new method for measuring anthropogenic environmental impact, which we monetize as an environmental cost. This is achieved using existing global maps of Net Primary Production (NPP) and Impervious Surface Area (ISA). The implicit assumption of setting these two global values to the same number ($50 trillion) is that human impact on the world is balanced by the earth's ability to absorb that impact. This equality assumption is in essence an assumption that humanity is presently at carrying capacity and this assumption would likely be contested by many (Brown, 2009; Wackernagel and Rees, 1996; Cohen, 1995). We make this simplifying assumption primarily because it is conceptually simpler and the resulting table of national deficits and surpluses will necessarily have a zero sum. The final map will present national ecological surpluses or deficits (in U.S. Dollars). This data set is summarized at the country level for easy comparison with other data sets such as poverty estimations, environmental sustainability indexes, and Eco Deficits.

The model presented here uses a simplifying albeit arbitrary axiom that the earth is presently at 'carrying capacity' (i.e. globally, human impacts on the environment are balanced by the environment's ability to absorb those impacts). This axiom of the model can be easily adjusted to 'set' human impact at .75, 1.5, or 3.0 times carrying capacity. It would be simple to produce scaling factors that would generate similar spatially explicit numbers using any corrective factor derived from other studies and/or metrics of sustainability. Other metrics that could be used include the Ecological Footprint itself, population to arable land ratios, freshwater availability, HANPP, etc. The power of this model is not the idea that the ratio of pavement and photosynthesis represent a fundamental measure of ecological sustainability but that ISA and NPP are valid proxy measures of human impact and ecosystem services that are relatively easy to map and measure globally.

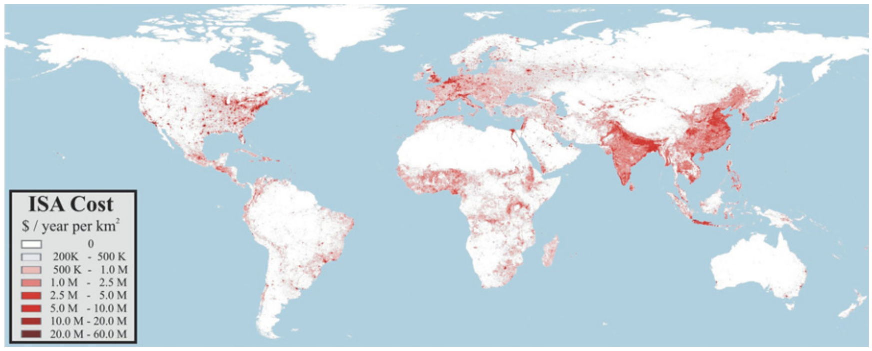

Fig. 1. Anthropogenic impervious surface area monetized to $50 Trillion for the year 2000.

2. Methods

2.1. Data: impervious surface area

Impervious surfaces are constructed, used, and maintained by humans around the globe. Current development practices and growing populations have lead to increasing and widespread existence of impervious surfaces. Elvidge et al., 2007 produced a global map of impervious surface area using nighttime satellite imagery, ambient population data, and impervious surface area data for the conterminous USA derived from Landsat. We monetize this global representation of impervious surface (Fig. 1) as a proxy measure of human impact or 'demand'. Data collected from the Defense Meteorological Satellite Program (DMSP) Operation Linescan System (OLS) detects nocturnal light emissions. These data can be used to map cities, gas flares, wild fires and other light sources. Algorithms have been developed for extracting the lights from the data and for creating annual composites (Elvidge et al., 1999, 2001). Certain criteria are used to ensure that only the best data are used in the composites. Only data from the center half of the orbital swath are used, no sunlit data, no moonlit data, no solar glare, no clouds, and no aurora emissions. These data are gridded in a 30″. The Landscan population product (Bhaduri et al., 2002) is developed at the Oak Ridge National Laboratory. This product is a measure of ambient population density modeled using census counts, road proximity, slope, and land cover. The data are also distributed in a 30″ grid. The United States Geological Survey (USGS) created a map of impervious surface area from Landsat data. The methodology for this process is described by Yang et al., 2003. This finer spatial resolution data is distributed in a 30 m grid.

The Landscan and DMSP OLS data were all converted into a 1 km resolution Mollweide projection. High resolution aerial photographs were used to develop regression parameters to create a model for predicting impervious surface area with nighttime lights and population (Elvidge et al., 2007). The USGS impervious surface product for the conterminous USA was used as calibration data for the model. The final product was a 1 km resolution grid distributed in a Mollweide equal area projection which is available from the National Geophysical Data Center. The study found that globally there are 579,703 km^2 of impervious surface area. Additionally, this dataset has been shown to have a strong correlation with Ecological Footprint data developed by Wackernagel and Rees, 1996. In an earlier work we demonstrated that the relationship between constructed area (ISA) per person and Ecological Footprint in global hectares (gha) per person is highly correlated (Sutton et al., 2009). This relationship has an R^2 value of 0.78 suggesting that ISA as used in this study will likely act as a good proxy measure of human impact (Fig. 2). The pixel values of the ISA data product range from 0 to 100 (% of pixel that is constructed surface e.g. pavement, rooftop, parking lot, etc.). We disaggregated $50 trillion dollars to those pixel values on a simple linear basis to produce a monetized map of human impact on the earth (Fig. 1).

2.2. Data: net primary productivity

In an identical manner we disaggregated $50 trillion dollars to a global dataset of NPP developed and disseminated at the Oak Ridge National Lab (www.daac.ornl.gov/NPP/npp_home.html). Net Primary Production (NPP) is "*the net amount of solar energy converted to plant organic matter through photosynthesis—it can be measured in units of elemental carbon and represents the primary food energy source for the world's ecosystems*" (Imhoff et al., 2004). "*From a biological perspective, NPP represents the primary energy source for the Earth's ecosystems and complex food webs by supplying food energy to the planet's heterotrophic organisms (organisms that require performed organic compounds for food, including human beings)*" (Imhoff and Bounoua, 2006). NPP data are distributed as a one quarter degree grid in a Platte Carree projection from the Oak Ridge National Laboratory Distributed Active Archive Center. "*The* Net Primary Production (NPP) *Database contains field measurements of biomass and estimated NPP for terrestrial sites worldwide, compiled from published literature and other extant data sources. It includes intensively studied and well documented field study sites, together with more extensive collections of worldwide data.* Imhoff et al., 2004 have studied the use of NPP required by humans compared to actual NPP. They found that human appropriation of NPP varies drastically and ranges from near zero use to many times the NPP available locally. Other studies of human appropriation of NPP suggest humanity consumes as much as 40% of the global total (Vitousek, 1994). Our model of the dollar value of earth's renewable natural endowment was produced by spreading $50 trillion

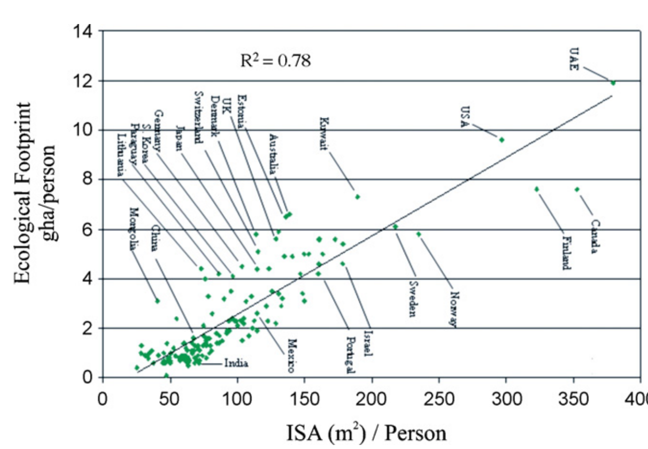

Fig. 2. Scatterplot of national Ecological Footprints per capita and ISA per capita (adapted from Sutton et al., 2009).

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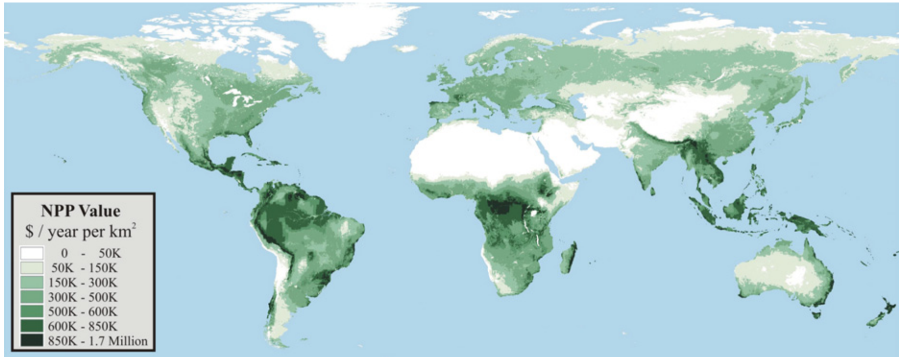

Fig. 3. Net primary productivity monetized to $50 Trillion for the year 2000.

in a simple linear allocation to the pixel values of this global NPP dataset (Fig. 3).

2.3. Analysis

Both the monetized ISA and monetized NPP images were summed to national levels. The $50 trillion number was chosen because it is within the range of the total global value of ecosystem services estimated by Costanza et al., 1997 and because this number is approximately the global GDP for the year 2000. In addition, the ISA data set is for the year 2000. Since the ISA image was in a 1 km^2 resolution Mollweide equal area projection the NPP image was converted to match. It was first re-sampled from a quarter degree resolution to a 1 km^2 resolution. Then it was re-projected from a Platte Carree projection to a matching Mollweide equal area projection for appropriate comparison and analysis. Once converted into the same resolution and projection the two images were subtracted as follows:

NPP (monetized to $50 trillion) – ISA (monetized to $50 trillion) = Ecological Balance

(i.e. Natural Production "supply" minus Human Impact "demand" = National Surplus or Deficit)

The subtraction described above was done with the rasterized monetization of NPP and ISA. This resulted in an image in which urban areas were generally in ecological deficit and non-urban vegetated areas were generally in ecological surplus. Not surprisingly, uninhabited deserts showed neither surplus nor deficit. We summed the resulting image to national or country levels of aggregation. For each country, the following numbers were calculated: Total Value of NPP ($NPP), Total Cost of ISA ($ISA), the difference between $NPP and $ISA (Eco-Balance), and Eco-Balance per capita (EB/capita) (Table 1, Figs. 4 and 5).

We conducted simple correlation analyses between the Ecological Balance and the Eco-Balance per capita numbers for each country and several other nationally aggregated metrics such as the percentage of the population in poverty, the percentage of the population living on less than two dollars a day, the ecological deficit (Wackernagel and Rees, 1996), and a Normalized Poverty Index developed at the National Geophysical Data Center (Elvidge et al., 2009).

3. Results

The twenty countries with the largest surplus Ecological Balance tended to be large forested countries with relatively large populations (Table 1). Brazil's surplus of $4.3 Trillion represents almost 9% of the total monetization of NPP. Only Canada, Australia, Congo, DRC, and Russia had surplus Ecological Balances that exceeded a trillion dollars (Table 1).

The twenty countries with the largest deficit Ecological Balance tended to be large populous and or wealthy countries with India, China, and the United states in the top three 'debtor nation' spots with deficit Ecological Balance figures of $5.7, $4.6, and $3.9 Trillion

Table 1
Top 20 countries with largest surplus ecological balance in the year 2000.

	Country	Population	Area (km^2)	Pop Den	NPP Dollars	ISA Dollars	Ecological balance	EB/Capita
1	Brazil	151,525,400	8,507,128	18	5,860,550,259,500	1,533,838,910,500	4,326,711,349,000	28,554
2	Russia	151,827,600	16,851,940	9	4,041,500,634,400	1,476,348,163,000	2,565,152,471,400	16,895
3	Congo, DRC	51,965,000	2,345,410	22	2,308,849,664,000	228,567,691,200	2,080,281,972,800	40,032
4	Australia	17,827,520	7,706,142	2	2,166,939,464,000	231,306,034,100	1,935,633,429,900	108,576
5	Canada	28,402,320	9,904,700	3	2,346,808,238,100	973,042,296,100	1,373,765,942,000	48,368
6	Angola	11,527,260	1,252,421	9	895,471,505,700	30,701,904,700	864,769,601,000	75,020
7	Peru	24,496,400	1,296,912	19	977,564,982,600	135,751,986,900	841,812,995,700	34,365
8	Colombia	34,414,590	1,141,962	30	973,137,393,100	284,496,371,300	688,641,021,800	20,010
9	Argentina	33,796,870	2,781,013	12	1,029,988,910,100	407,692,894,800	622,296,015,300	18,413
10	Bolivia	7,648,315	1,090,353	7	657,371,896,400	53,305,296,490	604,066,599,910	78,980
11	Venezuela	19,857,850	916,561	22	810,400,800,100	270,745,731,900	539,655,068,200	27,176
12	Zambia	8,778,681	754,773	12	569,490,092,200	42,025,947,610	527,464,144,590	60,085
13	Tanzania	35,306,000	945,090	37	649,069,756,300	146,454,093,500	502,615,662,800	14,236
14	Central African Republic	3,149,545	621,499	5	504,990,026,400	10,211,150,560	494,778,875,840	157,095
15	Mozambique	16,604,660	788,629	21	525,169,385,800	60,261,776,990	464,907,608,810	27,999
16	Indonesia	189,331,200	1,910,842	99	1,871,413,439,600	1,429,719,620,200	441,693,819,400	2,333
17	Papua New Guinea	4,039,033	466,161	9	444,236,634,700	23,017,645,370	421,218,989,330	104,287
18	Sudan	27,713,420	2,490,409	11	537,214,921,200	157,544,215,500	379,670,705,700	13,700
19	Madagascar	13,046,690	594,856	22	434,241,496,200	74,230,216,400	360,011,279,800	27,594
20	Congo	2,318,276	345,430	7	361,053,474,600	13,193,187,070	347,860,287,530	150,051

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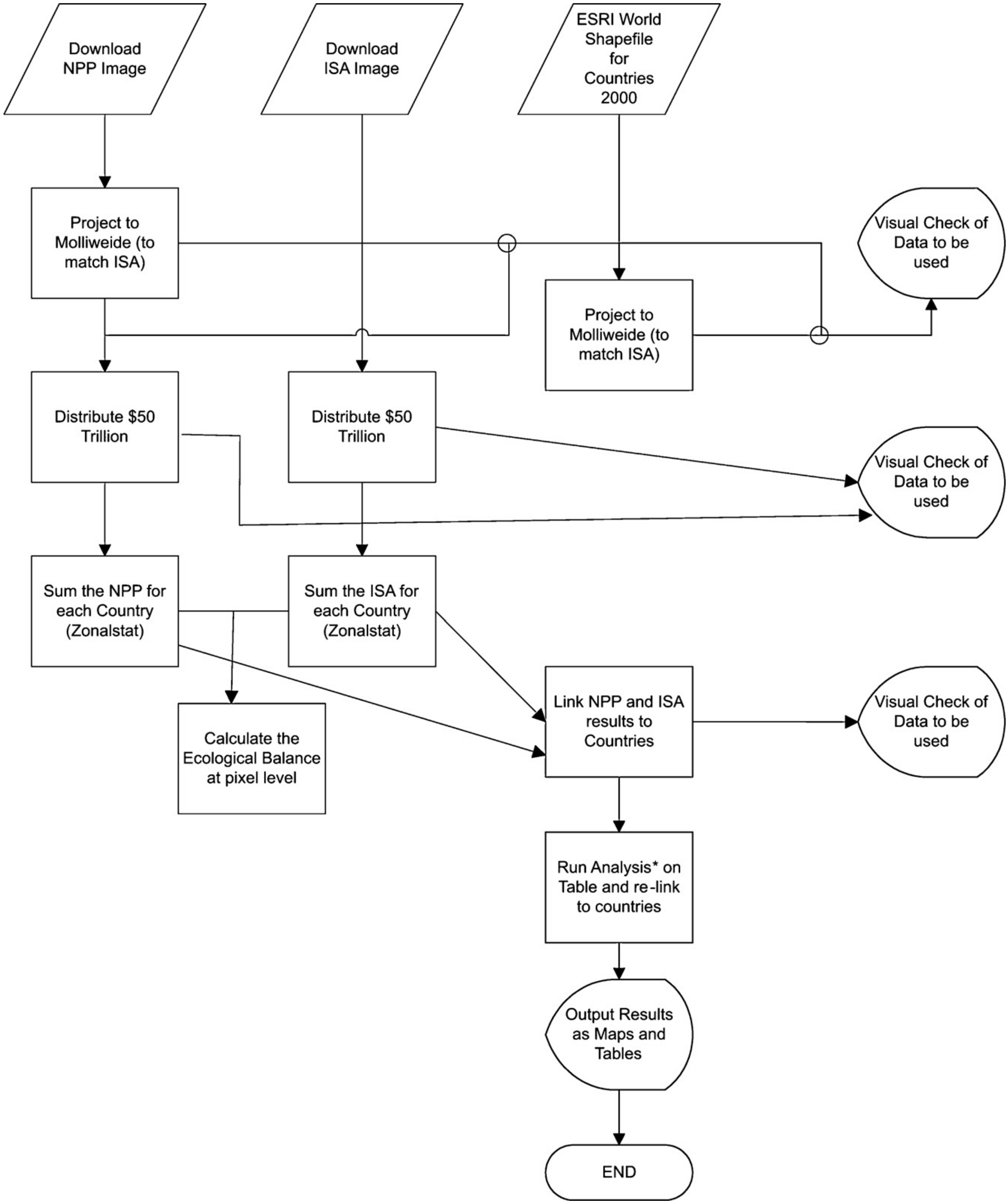

Fig. 4. Flow chart of data processing and analysis.

dollars respectively (Table 2). Japan's deficit approaches a trillion dollars but falls just short.

Examination of the per capita surpluses and deficits reveals some interesting patterns. The highest per capita deficits occur primarily in Middle Eastern nations such as Qatar ($45,046 per person), United Arab Emirates ($36,842 per person), Bahrain ($20,314), Kuwait ($19,155 per person), and Saudi Arabia ($19,205 per person). This is undoubtedly due to the minimal amount of photosynthesis taking place in these predominantly desert nations. Small island nations and protectorates also fare poorly by this per capita deficit metric (Aruba, $19,077; Guam, $15,627; Cyprus, $13,507; Virgin Islands, $13,405). The United States is far and away the most populous nation in the top 30 deficit per capita countries with a per capita deficit Ecological Balance of $15,213. Countries with high per capita surplus Ecological Balances are often in sub-Saharan Africa (Botswana, $$182,149; Central African Republic, $157,095; Congo,

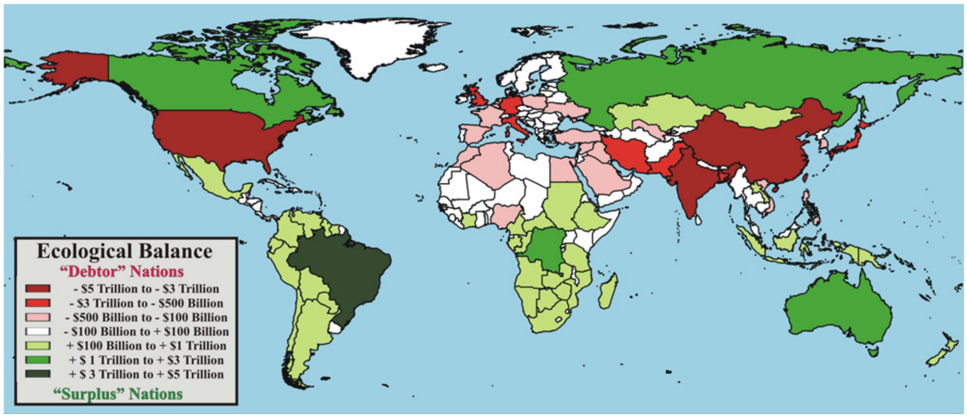

Fig. 5. National ecological balances expressed in Dollars for the year 2000.

$150,051; Namibia, $141,955; Gabon, $147,156; Angola, $75,020). This is likely due to their large areas, low population density, and high vegetation cover. Very large countries with very low populations such as Canada and Australia also have relatively high per capita surplus Ecological Balances (Canada, $48,368; Australia, $108,576). A summary of the monetized values of NPP, ISA, Ecological Balance, and the Eco-Balance per capita for all the nations of this study is provided in Table 3

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An interesting question to explore is assessing to what extent this Ecological Balance metric is a reasonable measure of the ‘Real Wealth of Nations’. One approach is to compare these national ‘Ecological Balance’ figures with other metrics of national wealth and well-being such as percentage of population in poverty, percentage of population living on less than $2 per day, and the Ecological Deficit metric developed by Wackernagel and Rees. The relationship between ecological balances and the percent of population in poverty are shown ($R = 0.11$, which is a weak relationship) (Fig. 6). Comparing the global distribution of poverty to the global distribution of NPP highlights interesting similarities and differences. Areas with relatively high values of natural production, such as Brazil and Central Africa, also tend to have relatively high levels of poverty. However, other areas such as North and South Africa and China, with moderate to low ecological deficits, also have relatively high poverty levels. This helps explain the poor correlation between the two data sets. The relationship between several measures of poverty (% of population living on less than $2 per day, percent of population in poverty, and total population in poverty) does not correlate strongly with either the Ecological Balance metric (or its normalized per capita measure) or the Ecological Deficit (or its normalized per capita measure) (Fig. 6). Nonetheless, there is a strong correlation ($R = 0.84$) between the sophisticated Ecological Deficit metric of Wackernagel and Rees (which is derived from hundreds of variables) and this simple Ecological Balance metric derived from spatially explicit measures of pavement and photosynthesis alone. The weak correlation between percentage of population living on less than $2 a day and both the Ecological Deficit and Ecological Balance metrics suggests that affluence rather than extreme poverty is a more significant driver of unsustainable lifestyles.

4. Discussion

By employing NPP as a proxy measure of the earth's natural production of ecosystem services and monetizing NPP as the dollar value of ecosystem service benefits we create a 1 km^2 resolution map of the earth's recurring natural endowment. A global 1 km^2 representation of the imposed cost of human activity is created using ISA as a proxy measure of human impact. Subtracting the $50 trillion monetization of human impact from the $50 trillion monetization of ecosystem services makes it possible to create a global map of the surplus or deficit value of natural production assuming humanity is presently at or about carrying capacity. The areas of

Table 2
Top 20 countries with the largest deficit ecological balance in the year 2000.

	Country	Population	Area (km)	Pop Den	NPP Dollars	ISA Dollars	Ecological balance	EB/capita
1	India	894,608,700	3,089,282	290	1,318,571,346,200	7,012,537,036,300	−5,693,965,690,100	−6,365
2	China	1,281,008,318	9,338,902	137	2,662,914,738,900	7,342,438,979,500	−4,679,524,240,600	−3,653
3	United States	258,833,000	9,450,720	27	3,308,986,500,100	7,246,569,183,500	−3,937,582,683,400	−15,213
4	Japan	125,746,300	373,049	337	221,450,517,500	1,205,271,117,200	−983,820,599,700	−7,824
5	Pakistan	126,693,000	877,753	144	105,015,078,200	919,936,455,000	−814,921,376,800	−6,432
6	Bangladesh	120,732,200	138,507	872	70,559,994,240	769,090,784,400	−698,530,790,160	−5,786
7	Germany	81,436,300	356,109	229	174,449,868,000	731,627,852,100	−557,177,984,100	−6,842
8	Italy	57,908,880	300,980	192	160,054,464,000	714,599,650,900	−554,545,186,900	−9,576
9	United Kingdom	56,420,180	243,137	232	123,103,601,100	652,264,827,100	−529,161,226,000	−9,379
10	Iran	64,193,450	1,624,760	40	84,144,201,690	598,284,006,000	−514,139,804,310	−8,009
11	France	57,757,060	546,729	106	333,820,137,700	821,151,541,300	−487,331,403,600	−8,438
12	Egypt	56,133,430	982,910	57	16,581,983,920	495,694,541,100	−479,112,557,180	−8,535
13	Spain	39,267,780	505,674	78	245,061,777,900	606,751,411,400	−361,689,633,500	−9,211
14	Saudi Arabia	18,099,990	1,960,175	9	5,020,630,739	349,377,198,000	−344,356,567,261	−19,025
15	South Korea	43,410,900	98,339	441	52,987,677,360	387,063,600,300	−334,075,922,940	−7,696
16	Nigeria	97,228,750	912,039	107	359,879,633,300	662,721,227,800	−302,841,594,500	−3,115
17	Poland	37,911,870	310,715	122	134,733,810,900	364,390,832,700	−229,657,021,800	−6,058
18	Vietnam	71,215,210	327,123	218	289,663,375,600	515,192,031,700	−225,528,656,100	−3,167
19	Philippines	65,981,120	298,134	221	277,171,911,700	466,853,553,300	−189,681,641,600	−2,875
20	Turkey	61,300,930	779,986	79	243,934,934,000	426,053,022,500	−182,118,088,500	−2,971

Table 3
Ecological Balance statistics for 200 nations of the world in the year 2000.

Country name	Pop country	Area (km^2)	NPP $50 Trillion	ISA $50 Trillion	Ecological balance	EB per captia
Afghanistan	1,725,0390	641,869	42,259,598,490.00	112,822,395,400.00	−70,562,796,910.00	−4,090.50
Albania	3,416,945	28,755	16,425,143,850.00	19,064,114,180.00	−2,638,970,330.00	−772.32
Algeria	27,459,230	2,320,972	44,025,169,480.00	210,999,159,100.00	−166,973,989,620.00	−6,080.80
American Samoa	53,000	187	233,889,519.20	510,956,105.40	−277,066,586.20	−5,227.67
Andorra	55,335	452	233,341,945.20	1,250,154,147.00	−1,016,812,201.80	−18,375.57
Angola	11,527,260	1,252,421	895,471,505,700.00	30,701,904,700.00	864,769,601,000.00	75,019.53
Anguilla	9208	86	61,028,271.70	164,001,501.50	−102,973,229.80	−11,183.02
Argentina	33,796,870	2,781,013	1,029,988,910,100.00	407,692,894,800.00	622,296,015,300.00	18,412.83
Armenia	3,377,228	29,872	10,849,266,500.00	16,107,415,410.00	−5,258,148,910.00	−1,556.94
Aruba	67,074	183	64,541,051.91	1,344,122,779.00	−1,279,581,727.09	−19,077.16
Australia	17,827,520	7,706,142	2,166,939,464,000.00	231,306,034,100.00	1,935,633,429,900.00	108,575.59
Austria	7,755,406	83,739	43,793,680,110.00	94,426,801,580.00	−50,633,121,470.00	−6,528.75
Azerbaijan	5,487,866	85,808	31,259,372,060.00	50,503,803,840.00	−19,244,431,780.00	−3,506.72
Bahrain	575,814	657	213,564.80	11,697,271,370.00	−11,697,057,805.20	−20,313.95
Bangladesh	120,732,200	138,507	70,559,994,240.00	769,090,784,400.00	−698,530,790,160.00	−5,785.79
Barbados	260,627	440	491,842,785.20	2,960,278,745.00	−2,468,435,959.80	−9,471.14
Belgium	10,032,460	30,480	13,982,810,730.00	143,354,418,400.00	−129,371,607,670.00	−12,895.30
Belize	207,586	22,175	22,261,233,620.00	2,273,202,609.00	19,988,031,011.00	96,287.95
Benin	5,175,394	116,515	55,878,890,020.00	35,628,031,250.00	20,250,858,770.00	3,912.91
Bermuda	59,973	39	14,433,548.30	92,627,589.11	−78,194,040.81	−1,303.82
Bhutan	1,586,631	39,927	34,941,342,810.00	10,525,954,370.00	24,415,388,440.00	15,388.20
Bolivia	7,648,315	1,090,353	657,371,896,400.00	53,305,296,490.00	604,066,599,910.00	78,980.35
Bosnia & Herzegovina	3,836,000	51,233	28,200,499,010.00	33,359,197,980.00	−5,158,698,970.00	−1,344.81
Botswana	1,446,623	580,011	273,221,946,600.00	9,720,494,661.00	263,501,451,939.00	182,149.36
Brazil	151,525,400	8,507,128	5,860,550,259,500.00	1,533,838,910,500.00	4,326,711,349,000.00	28,554.36
Brunei	281,614	5770	5,959,583,556.00	6,199,728,380.00	−240,144,824.00	−852.74
Bulgaria	8,943,258	110,802	58,801,689,290.00	68,671,258,030.00	−9,869,568,740.00	−1,103.58
Burkina Faso	1,016,4690	273,719	54,444,486,550.00	57,986,940,050.00	−3,542,453,500.00	−348.51
Burundi	6,011,039	27,254	22,219,154,580.00	39,338,302,420.00	−17,119,147,840.00	−2,847.95
Cambodia	9,129,576	182,612	141,894,898,600.00	73,218,374,800.00	68,676,523,800.00	7,522.42
Cameroon	13,218,480	466,307	374,250,992,000.00	67,495,315,980.00	306,755,676,020.00	23,206.58
Canada	28,402,320	9,904,700	2,346,808,238,100.00	973,042,296,100.00	1,373,765,942,000.00	48,368.09
Cape Verde	413,573	3962	890,234,031.30	2,246,308,368.00	−1,356,074,336.70	−3,278.92
Central African Republic	3,149,545	621,499	504,990,026,400.00	10,211,150,560.00	494,778,875,840.00	157,095.35
Chad	6,308,708	1,168,002	74,910,529,910.00	23,469,588,690.00	51,440,941,220.00	8,153.96
Chile	13,772,710	742,298	267,416,131,900.00	122,388,251,000.00	145,027,880,900.00	10,530.09
China	1,281,008,318	9,338,902	2,662,914,738,900.00	7,342,438,979,500.00	−4,679,524,240,600.00	−3,653.00
Colombia	34,414,590	1,141,962	973,137,393,100.00	284,496,371,300.00	688,641,021,800.00	20,010.15
Comoros	634,656	1660	2,550,000,824.00	3,036,847,838.00	−486,847,014.00	−767.10
Congo	2,318,276	345,430	361,053,474,600.00	13,193,187,070.00	347,860,287,530.00	150,051.28
Congo, DRC	51,965,000	2,345,410	2,308,849,664,000.00	228,567,691,200.00	2,080,281,972,800.00	40,032.37
Costa Rica	3,319,438	51,608	48,041,477,340.00	37,710,750,590.00	10,330,726,750.00	3,112.19
Cote d'lvory	15,981,000	322,460	217,714,773,000.00	85,284,983,370.00	132,429,789,630.00	8,286.70
Croatia	5,004,112	56,288	27,325,036,360.00	50,049,414,580.00	−22,724,378,220.00	−4,541.14
Cuba	11,102,280	110,443	94,583,192,080.00	74,005,078,590.00	20,578,113,490.00	1,853.50
Cyprus	739,027	9227	3,478,078,668.00	13,460,461,790.00	−9,982,383,122.00	−13,507.47
Czech Republic	10,321,120	78,495	38,858,081,820.00	123,987,007,400.00	−85,128,925,580.00	−8,248.03
Denmark	4,667,750	42,671	19,092,408,580.00	51,362,662,900.00	−32,270,254,320.00	−6,913.45
Djibouti	450,751	21,638	292,743,342.80	751,262,093.10	−458,518,750.30	−1,017.23
Dominica	70,671	732	1,378,225,218.00	439,229,977.40	938,995,240.60	13,286.85
Dominican Republic	7,759,957	48,445	50,997,174,770.00	58,320,144,020.00	−7,322,969,250.00	−943.69
Ecuador	10,541,820	256,932	219,113,764,500.00	97,437,866,970.00	121,675,897,530.00	11,542.21
Egypt	56,133,430	982,910	16,581,983,920.00	495,694,541,100.00	−479,112,557,180.00	−8,535.24
El Salvador	5,752,470	20,697	21,187,944,830.00	47,781,693,100.00	−26,593,748,270.00	−4,623.01
Equatorial Guinea	386,373	27,085	23,636,726,430.00	1,635,423,316.00	22,001,303,114.00	56,943.17
Country name	Pop country	Area (km^2)	NPP $50 Trillion	ISA $50 Trillion	Ecological balance	EB per captia
Eritrea	3,662,271	121,941	13,963,028,110.00	18,888,895,810.00	−4,925,867,700.00	−1,345.03
Estonia	1,590,808	45,545	18,654,240,070.00	15,146,493,860.00	3,507,746,210.00	2,205.01
Ethiopia	53,142,970	1,132,328	571,238,831,600.00	354,206,821,000.00	217,032,010,600.00	4,083.93
Fiji	7,550,00	19,364	26,770,904,570.00	4,796,280,397.00	21,974,624,173.00	29,105.46
Finland	5,031,379	333,797	112,454,871,300.00	142,987,527,100.00	−30,532,655,800.00	−6,068.45
France	57,757,060	546,729	333,820,137,700.00	821,151,541,300.00	−487,331,403,600.00	−8,437.61
French Guiana	130,219	83,811	76,561,777,070.00	1,564,268,649.00	74,997,508,421.00	575,933.68
French Polynesia	217,000	3024	3,994,918,589.00	1,553,717,746.00	2,441,200,843.00	11,249.77
Gabon	1,561,195	261,689	236,636,133,000.00	6,897,422,126.00	229,738,710,874.00	147,155.68
Gaza Strip	728,583	374	88,380,960.00	6,080,032,888.00	−5,991,651,928.00	−8,223.71
Georgia	5,595,552	69,943	39,443,472,330.00	22,279,304,520.00	17,164,167,810.00	3,067.47
Germany	81,436,300	356,109	174,449,868,000.00	731,627,852,100.00	−557,177,984,100.00	−6,841.89
Ghana	16,698,090	239,981	138,793,072,200.00	118,679,314,000.00	20,113,758,200.00	1,204.55
Greece	10,307,460	131,852	70,249,155,820.00	133,313,827,800.00	−63,064,671,980.00	−6,118.35
Greenland	55,413	2,142,661	4,690,162,716.00	117,146,153.20	4,573,016,562.80	82,526.06
Grenada	95,608	367	601,308,405.10	769,227,534.70	−167,919,129.60	−1,756.33
Guadeloupe	410,638	1743	2,596,091,036.00	4,895,218,738.00	−2,299,127,702.00	−5,598.92

Table 3
(*Continued*).

Country name	Pop country	Area (km^2)	NPP $50 Trillion	ISA $50 Trillion	Ecological balance	EB per captia
Guam	143,173	572	722,361,609.30	2,959,711,732.00	−2,237,350,122.70	−15,626.90
Guatemala	10,321,270	109,502	123,227,105,800.00	96,657,833,930.00	26,569,271,870.00	2,574.23
Guernsey	62,920	78	44,276,004.29	421,401,286.20	−377,125,281.91	−5,993.73
Guinea	62,420,070	246,077	109,488,572,100.00	31,591,338,040.00	77,897,234,060.00	1,247.95
Guinea-Bissau	1,085,777	33,635	8,691,431,415.00	5,602,218,181.00	3,089,213,234.00	2,845.16
Guyana	754,931	211,241	203,116,078,100.00	4,718,577,277.00	198,397,500,823.00	262,802.16
Haiti	7,044,890	27,157	28,666,538,050.00	37,764,338,950.00	−9,097,800,900.00	−1,291.40
Honduras	5,367,067	112,852	130,312,779,200.00	44,479,227,120.00	85,833,552,080.00	15,992.64
Hungary	10,310,410	92,782	39,184,658,900.00	108,528,544,800.00	−69,343,885,900.00	−6,725.62
Iceland	267,240	101,805	9,335,492,126.00	2,958,566,586.00	6,376,925,540.00	23,862.17
India	894,608,700	3,089,282	1,318,571,346,200.00	7,012,537,036,300.00	−5,693,965,690,100.00	−6,364.76
Indonesia	189,331,200	1,910,842	1,871,413,439,600.00	1,429,719,620,200.00	441,693,819,400.00	2,332.92
Iran	64,193,450	1,624,760	84,144,201,690.00	598,284,006,000.00	−514,139,804,310.00	−8,009.23
Iraq	20,941,720	436422	9,757,211,555.00	154,639,103,800.00	−144,881,892,245.00	−6,918.34
Ireland	5,015,975	69,384	41,246,313,320.00	53,923,119,130.00	−12,676,805,810.00	−2,527.29
Israel	5,694,890	20,774	3,855,019,440.00	89,706,578,850.00	−85,851,559,410.00	−15,075.19
Italy	57,908,880	300,980	160,054,464,000.00	714,599,650,900.00	−554,545,186,900.00	−9,576.17
Jamaica	2,407,607	11,044	13,831,216,880.00	23,790,340,580.00	−9,959,123,700.00	−4,136.52
Japan	125,746,300	373,049	221,450,517,500.00	1,205,271,117,200.00	−983,820,599,700.00	−7,823.85
Jersey	87,848	120	108,999,471.60	735,628,078.60	−626,628,607.00	−7,133.10
Jordan	3,950,283	89,275	3,739,099,878.00	44,898,594,940.00	−41,159,495,062.00	−10,419.38
Kazakhstan	17,117,910	2,715,976	361,301,577,000.00	100,126,624,000.00	261,174,953,000.00	15,257.41
Kenya	25,835,250	584,429	242,196,031,300.00	180,118,033,600.00	62,077,997,700.00	2,402.84
Kiribati	77,000	1050	91,244,520.73	68,392,531.86	22,851,988.87	296.78
Kuwait	1,639,000	16,984	7,725,056.18	31,402,333,460.00	−31,394,608,403.82	−19,154.73
Kyrgyzstan	4,478,697	199,340	37,112,074,850.00	32,558,485,620.00	4,553,589,230.00	1,016.72
Laos	4,722,773	230,566	250,199,792,800.00	30,694,678,060.00	219,505,114,740.00	46,478.02
Latvia	2,690,291	64,299	26,483,127,650.00	15,447,789,410.00	11,035,338,240.00	4,101.91
Lebanon	2,942,959	10,240	3,974,819,016.00	34,909,813,830.00	−30,934,994,814.00	−10,511.53
Lesotho	1,928,269	30,352	15,090,309,230.00	7,705,305,546.00	7,385,003,684.00	3,829.86
Liberia	2,902,441	96,296	63,761,442,040.00	13,824,462,380.00	49,936,979,660.00	17,205.17
Libya	5,245,515	1,620,515	8,929,336,477.00	61,642,066,360.00	−52,712,729,883.00	−10,049.10
Liechtenstein	29,342	165	93,412,738.96	498,521,827.40	−405,109,088.44	−13,806.46
Lithuania	3,786,560	64,849	25,490,280,870.00	23,493,492,210.00	1,996,788,660.00	527.34
Luxembourg	387,064	2594	1,359,371,622.00	6,917,845,739.00	−5,558,474,117.00	−14,360.61
Macedonia	2,104,035	25,321	13,732,850,290.00	19,314,934,380.00	−5,582,084,090.00	−2,653.04
Madagascar	13,046,690	594,856	434,241,496,200.00	74,230,216,400.00	360,011,279,800.00	27,594.07
Malawi	10,660,480	119,028	70,780,554,000.00	69,346,449,120.00	1,434,104,880.00	134.53

Country name	Pop country	Area (km^2)	NPP $50 Trillion	ISA $50 Trillion	Ecological balance	EB per captia
Maldives	11,511	165	7,996,438.67	81,569,153.24	−73,572,714.57	−6,391.51
Mali	9,744,733	1,256,747	29,850,762,500.00	35,384,104,150.00	−5,533,341,650.00	−567.83
Malta	366,410	332	186,965,377.10	4,292,850,009.00	−4,105,884,631.90	−11,205.71
Martinique	374,574	1101	1,807,857,693.00	4,830,490,226.00	−3,022,632,533.00	−8,069.52
Mauritania	2,204,077	1,041,570	154,968,911.40	7,351,666,850.00	−7,196,697,938.60	−3,265.18
Mauritius	1,097,234	2035	2,728,798,495.00	9,651,274,512.00	−6,922,476,017.00	−6,309.02
Mayotte	100,838	393	611,025,931.20	1,238,224,622.00	−627,198,690.80	−6,219.86
Mexico	92,380,850	1,962,939	1,145,588,233,400.00	1,023,484,284,300.00	122,103,949,100.00	1,321.75
Moldova	4,473,570	33,567	12,860,994,420.00	25,778,112,920.00	−12,917,118,500.00	−2,887.43
Monaco	27,409	12	4,460,596.96	412,002,199.30	−407,541,602.35	−14,868.90
Mongolia	2,228,222	1,559,176	147,322,548,400.00	9,316,191,619.00	138,006,356,781.00	61,935.64
Montserrat	12,771	105	101,764,936.80	43,547,990.41	58,216,946.39	4,558.53
Morocco	27,767,920	403,860	56,923,324,610.00	157,122,846,400.00	−100,199,521,790.00	−3,608.46
Mozambique	16,604,660	788,629	525,169,385,800.00	60,261,776,990.00	464,907,608,810.00	27,998.62
Namibia	1,575,611	826,800	234,163,852,700.00	10,435,676,890.00	223,728,175,810.00	141,994.55
Nauru	10,000	28	21,502,062.14	43,229,128.56	−21,727,066.42	−2,172.71
Nepal	19,927,280	147,293	89,851,212,630.00	152,535,594,000.00	−62,684,381,370.00	−3,145.66
Netherlands	15,447,470	35,493	15,550,336,980.00	169,756,135,200.00	−154,205,798,220.00	−9,982.59
Netherlands Antilles	191,572	804	485,100,302.00	3,252,802,252.00	−2,767,701,950.00	−14,447.32
New Caledonia	178,000	19,141	21,910,939,270.00	1,944,334,632.00	19,966,604,638.00	112,171.94
New Zealand	3,528,197	266,820	271,155,155,300.00	41,388,001,550.00	229,767,153,750.00	65,123.11
Nicaragua	4,275,103	129,047	115,247,389,500.00	32,337,461,430.00	82,909,928,070.00	19,393.67
Niger	8,797,739	1,186,021	18,548,004,160.00	36,422,962,290.00	−17,874,958,130.00	−2,031.77
Nigeria	97,228,750	912,039	359,879,633,300.00	662,721,227,800.00	−302,841,594,500.00	−3,114.73
Niue	2000	228	362,609,852.60	17,404,653.93	345,205,198.67	172,602.60
North Korea	22,034,990	122,473	70,556,824,650.00	92,272,816,390.00	−21,715,991,740.00	−985.52
Norway	4,328,519	316,962	77,484,455,680.00	84,829,927,030.00	−7,345,471,350.00	−1,696.99
Oman	2,090,308	309,652	2,400,013,633.00	38,589,399,550.00	−36,189,385,917.00	−17,312.94
Pakistan	126,693,000	877,753	105,015,078,200.00	919,936,455,000.00	−814,921,376,800.00	−6,432.25
Panama	2,562,045	74,697	66,726,648,240.00	23,156,063,430.00	43,570,584,810.00	17,006.17
Papua New Guinea	4,039,033	466,161	444,236,634,700.00	23,017,645,370.00	421,218,989,330.00	104,287.09
Paraguay	4,773,464	400,089	167,379,496,100.00	45,445,596,440.00	121,933,899,660.00	25,544.11
Peru	24,496,400	1,296,912	977,564,982,600.00	135,751,986,900.00	841,812,995,700.00	34,364.76
Philippines	65,981,120	298,134	277,171,911,700.00	466,853,553,300.00	−189,681,641,600.00	−2,874.79
Poland	37,911,870	310,715	134,733,810,900.00	364,390,832,700.00	−229,657,021,800.00	−6,057.65

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Table 3
(*Continued*).

Country name	Pop country	Area (km^2)	NPP $50 Trillion	ISA $50 Trillion	Ecological balance	EB per captia
Portugal	9,625,516	92,098	51,285,498,170.00	140,700,571,600.00	−89,415,073,430.00	−9,289.38
Puerto Rico	3,647,931	9063	9,838,560,725.00	56,319,586,080.00	−46,481,025,355.00	−12,741.75
Qatar	478,000	11,099	1,408,937.45	21,533,514,670.00	−21,532,105,732.55	−45,046.25
Reunion	644,000	2576	3,720,989,496.00	5,900,456,297.00	−2,179,466,801.00	−3,384.27
Romania	23,540,550	236,654	124,596,587,300.00	184,848,707,200.00	−60,252,119,900.00	−2,559.50
Russia	151,827,600	1,685,1940	4,041,500,634,400.00	1,476,348,163,000.00	2,565,152,471,400.00	16,895.17
Rwanda	7,934,396	25,228	20,907,927,940.00	49,803,263,900.00	−28,895,335,960.00	−3,641.78
San Marino	23,758	63	21,278,551.39	446,817,955.60	−425,539,404.21	−17,911.42
Saudi Arabia	18,099,990	1,960,175	5,020,630,739.00	349,377,198,000.00	−344,356,567,261.00	−19,025.24
Senegal	8,116,554	196,911	22,589,231,550.00	49,307,849,530.00	−26,718,617,980.00	−3,291.87
Serbia & Montenegro	10,662,000	132,350	47,328,756,750.00	86,170,747,790.00	−38,841,991,040.00	−3,643.03
Seychelles	73,000	489	337,883,770.80	597,029,905.00	−259,146,134.20	−3,549.95
Sierra Leone	4,551,746	72,531	46,797,795,760.00	23,955,664,010.00	22,842,131,750.00	5,018.32
Singapore	2,824,024	526	151,112,941.00	30,474,543,300.00	−30,323,430,359.00	−10,737.67
Slovakia	5,374,362	48,648	23,281,513,750.00	62,690,930,620.00	−39,409,416,870.00	−7,332.85
Slovenia	1,951,443	20,246	12,150,022,570.00	24,949,161,050.00	−12,799,138,480.00	−6,558.81
Somalia	9,951,515	639,065	112,829,757,300.00	18,270,517,280.00	94,559,240,020.00	9,501.99
South Africa	40,634,126	1,221,943	543,222,933,900.00	400,128,264,300.00	143,094,669,600.00	3,521.54
South Korea	43,410,900	98,339	52,987,677,360.00	387,063,600,300.00	−334,075,922,940.00	−7,695.67
Spain	39,267,780	505,674	245,061,777,900.00	606,751,411,400.00	−361,689,633,500.00	−9,210.85
Sri Lanka	18,321,920	66,580	55,703,688,200.00	133,962,002,300.00	−78,258,314,100.00	−4,271.29
St. Helena	6782	391	227,709,911.50	59,560,014.09	168,149,897.41	24,793.56
St. Lucia	141,743	605	1,099,159,203.00	1,522,520,871.00	−423,361,668.00	−2,986.83
Sudan	27,713,420	2,490,409	537,214,921,200.00	157,544,215,500.00	379,670,705,700.00	13,699.89
Suriname	428,026	145,498	116,518,504,400.00	4,204,384,746.00	112,314,119,654.00	262,400.23
Svalbard	3148	61,937	52,977,075.63	-	52,977,075.63	16,828.80
Swaziland	842,766	17,164	15,106,047,890.00	7,965,086,788.00	7,140,961,102.00	8,473.24
Sweden	8,728,217	443,800	156,138,380,800.00	163,208,794,100.00	−7,070,413,300.00	−810.06
Switzerland	6,713,839	41,178	20,975,254,400.00	74,137,492,970.00	−53,162,238,570.00	−7,918.31
Syria	140,454,70	187,937	18,227,984,850.00	131,808,461,800.00	−113,580,476,950.00	−8,086.63
Tajikistan	5,382,232	142,410	14,020,736,510.00	43,496,514,460.00	−29,475,777,950.00	−5,476.50
Tanzania	35,306,000	945,090	649,069,756,300.00	146,454,093,500.00	502,615,662,800.00	14,235.98
Thailand	57,323,780	515,144	384,252,688,300.00	478,297,225,000.00	−94,044,536,700.00	−1,640.59
The Gambia	1,367,000	11,300	2,014,788,209.00	7,735,435,100.00	−5,720,646,891.00	−4,184.82
Togo	4,048,365	57,300	30,200,728,970.00	26,871,893,570.00	3,328,835,400.00	822.27
Tonga	98,000	697	813,442,513.60	536,818,603.30	276,623,910.30	2,822.69
Tunisia	8,620,181	155,402	14,063,799,220.00	85,233,840,950.00	−71,170,041,730.00	−8,256.21
Turkey	61,300,930	779,986	243,934,934,000.00	426,053,022,500.00	−182,118,088,500.00	−2,970.89
Turkmenistan	3,714,642	471,429	16,911,184,100.00	40,893,810,150.00	−23,982,626,050.00	−6,456.24
Tuvalu	13,000	31	1,320,844.71	7,631,782.76	−6,310,938.06	−485.46
Uganda	18,144,360	243,050	182,441,606,900.00	149,800,586,500.00	32,641,020,400.00	1,798.96
Ukraine	531,649,20	596,041	232,248,983,100.00	368,316,569,100.00	−136,067,586,000.00	−2,559.35
United Arab Emirates	2,061,800	71,234	27,800,802.77	75,988,514,930.00	−75,960,714,127.23	−36,841.94
United Kingdom	56,420,180	243,137	123,103,601,100.00	652,264,827,100.00	−529,161,226,000.00	−9,378.94
United States	258,833,000	9,450,720	3,308,986,500,100.00	7,246,569,183,500.00	−3,937,582,683,400.00	−15,212.83
Uruguay	3,084,641	178,141	118,181,992,700.00	33,761,666,570.00	84,420,326,130.00	27,367.96
Uzbekistan	20,841,790	445,711	34,278,352,000.00	191,973,068,200.00	−157,694,716,200.00	−7,566.28
Vanuatu	165,000	12,535	17,573,409,840.00	876,399,804.90	16,697,010,035.10	101,194.00
Venezuela	19,857,850	916,561	810,400,800,100.00	270,745,731,900.00	539,655,068,200.00	27,175.91
Vietnam	71,215,210	327,123	289,663,375,600.00	515,192,031,700.00	−225,528,656,100.00	−3,166.86
West Bank	1,427,741	5816	1,500,953,933.00	24,884,343,590.00	−23,383,389,657.00	−16,377.89
Western Sahara	222,631	269,602	38,753,266.76	1,404,793,251.00	−1,366,039,984.24	−6,135.89
Yemen	15,351,120	425,521	27,770,637,010.00	117,089,451,900.00	−89,318,814,890.00	−5,818.39
Zambia	8,778,681	754,773	569,490,092,200.00	42,025,947,610.00	527,464,144,590.00	60,084.67
Zimbabwe	11,106,690	390,804	245,713,183,300.00	58,946,082,730.00	186,767,100,570.00	16,815.73

highest surplus values are found in Russia, Brazil, Australia, Canada, Central Africa, Central America, and parts of Southeast Asia. These regions are operating their national economies below the carrying capacity of national ecosystems. This follows an expected pattern, based on the high NPP values in these areas of tropical rainforest combined with relatively low levels of consumption. However, many of these areas are rapidly deforesting and losing vital ecosystem services associated with highly-productive tropical rainforests such as climate regulation, erosion control, and the provision of raw materials (Costanza et al., 1997; Achard et al., 2002; Malhi et al., 2009).

In Northern Africa and the Middle East, where human development and consumption levels are relatively low, the natural production values are also low. These desert environments are not endowed with an ecological surplus, so they cannot sustain high levels of human consumption and environmental impact without drawing on natural resources from other regions. For example, Phoenix, Arizona, is struggling with scarcity of water resources in the face of high demand for landscaping and human use (Farber et al., 2006). Quite simply, low levels of rainfall and high evapotranspiration limits the amount of biomass these areas can support, and by extension, limits the amount of NPP.

In regions such as North America, China, India, and Europe, the map shows ecological deficits, which suggests that high levels of human development and population are exceeding natural production values. The economies of these countries have an impact

Correlation Matrix of Monetized NPP and ISA, Ecological Balance, and Eco-Balance per capita with other metrics of poverty, and sustainability.	NPP_$	ISA_$	Ecological Balance (EB)	Eco-Balance / Capita	% Pop in Poverty	Total Pop in Poverty	% Pop 2$ per Day	Total Eco-Deficit	Eco_Deficit/Capita
NPP_$	1.00	0.55	0.22	0.20	-0.04	0.36	-0.02	0.02	0.07
ISA_$	0.55	1.00	-0.70	-0.11	-0.12	0.80	0.05	-0.62	-0.12
Ecological Balance (EB)	0.22	-0.70	1.00	0.31	0.11	-0.63	-0.08	**0.84**	0.37
Eco-Balance / Capita	0.20	-0.11	0.31	1.00	0.25	-0.06	0.08	0.19	0.71
% Pop in Poverty	-0.04	-0.12	0.11	0.25	1.00	0.08	0.56	0.10	0.22
Total Pop in Poverty	0.36	0.80	-0.63	-0.06	0.08	1.00	0.21	-0.42	-0.03
% Pop 2$ per Day	-0.02	0.05	-0.08	0.08	0.56	0.21	1.00	0.02	0.07
Total Eco-Deficit	0.02	-0.62	**0.84**	0.19	0.10	-0.42	0.02	1.00	0.38
Eco_Deficit (GHA per person)	0.07	-0.12	0.37	0.71	0.22	-0.03	0.07	0.38	1.00

Fig. 6. Correlation matrix of sustainability metrics.

on the environment that is greater than its ability to sustain itself; national production and consumption levels have overshot ecological capacity. Indeed, "*[if] international trade suddenly ceased, [these] countries would find themselves well beyond sustainable scale*" (Daly and Farley, 2004: 333)

The ecological balances (derived from NPP minus ISA) were joined with other measures of Ecological Deficit and poverty estimates. While it was thought that poverty might correlate with NPP, as areas with lower natural production would not have a large resource base to support high consumption levels, the relationship was not found to be very strong. Poverty can be associated with areas of high NPP (e.g., Central Africa) and areas of low NPP (e.g., the Middle East). People inhabiting Central Africa do not benefit from the regional surplus of natural production, as the goods and services provided by rainforests and mineral deposits are largely exported to more developed countries. For example, China—a country exhibiting an ecological deficit—increasingly relies upon tropical African countries for timber and non-renewable resources. China initiates "*resource for infrastructure*" swaps which allow them to mine copper and cobalt in exchange for building roads and schools in countries such as Gabon and the Democratic Republic of the Congo (Laurance et al., 2006; French, 2010). China has become the biggest investor in Africa, using Africa's wealth of renewable and non-renewable natural resources to supply growing global demands for goods.

Unlike poverty, ecological deficit was found to correlate very highly with the ecological balances ($R^2 = 0.71$). The Ecological Deficit of Wackernagel and Rees correlate strongly with the ecological balances figures (Fig. 6). The USA and Europe tend to have high human impacts and low natural production values. Places like Brazil and Central Africa tend to have low human impacts and high natural production value. However, the interconnected global economy allows more developed (or even over-developed) countries to harness the ecological surpluses from many tropical countries. Raw material extraction has been increasingly outsourced to countries with the lowest environmental standards in a global "*race to the bottom*" in the quest for resources (Daly and Farley, 2004).

Ecological accounting provides a sense of global flows of goods, but it also shows what countries are providing global (and often ignored or undervalued) ecosystem services. Tropical rainforests are one of the most important terrestrial providers of ecosystem services (Costanza et al., 1997); yet, globally it is estimated that about six million areas of rainforest were lost annually between 1990 and 1997 (Achard et al., 2002). Countries with large swaths of tropical forest face increasing demands for goods. One example is Gabon, which has exhausted its oil reserves and is replacing that lost income through increased exploitation of forest resources (Laurance et al., 2006). While these rainforests are being harvested for their stocks, global benefits from climate regulation, nutrient cycling, and carbon uptake are lost—potentially forever. As Costanza et al., 1997 noted, "*if significant, irreversible thresholds are passed for irreplaceable ecosystem services, their value may quickly jump to infinity*". It is vital that humans do not push ecosystems beyond that critical tipping point.

We examine the relationship of NPP and ISA as it relates to poverty; however we do not assume that each national ecological balance determines poverty. However, poor deficit countries are more likely to be ecologically vulnerable than wealthy deficit countries. Like Costanza et al., 1997, we too acknowledge the empirical and conceptual challenges of our study. Developing a global indicator for monetizing ecosystem services raises the question of whether accuracy is possible. We are confident that we do a better job valuing ecosystem services than the unregulated market; however, if an ecosystem service is irreplaceable or can be irreversibly damaged, then it is important to consider whether or not it is beneficial to place a market value on that ecosystem service at all. We do not advocate the notion that ecosystem services must be assigned a monetary value so they can be included in the market. At their very core, particularly with increasing scarcity, ecosystem services are irreplaceable. In all likelihood, auctioning off ecosystem services would not provide adequate compensation to all those impacted by the rapid loss of critical functions (e.g., water filtration, nutrient cycling, carbon sequestration, etc.). The market cannot adequately price these services; while we recognize that ecosystem services have a monetary value, we argue that the market should not be in charge of allocating them. These ecosystem services undergird provisioning, regulating, cultural, and supporting processes that are essential to human life and therefore should not be considered as a renewable resource, which is how they are treated currently within the market (Newman and Jennings, 2008). Part of our motivation for developing this new method of measuring global consumption of ecosystem services is that, whether the market acknowledges it or not, there are limits to environmental systems for production of resources, and more importantly, there are limits to the global sinks that absorb the waste produced around the world (Daly and Farley, 2004).

There are several paths of exploration that are likely worth future examination. It would be beneficial to compare ecological balances with Gross Domestic Product (GDP) at the national scale. It would also be useful to explore the relationship between HANPP and ecological balances. It seems that this data and HANPP might help answer different questions within the same field of study and could be used together to better answer questions and inform policy decisions. It might also be interesting to further examine the relationship with poverty to determine if there are any relationships that have been overlooked. In order to examine how countries export the environmental impact of national consumption, it might be interesting to compare ecological balances with the importance of basic export goods to a nation's economy.

Productivity of marine ecosystems was not included in this analysis. Nevertheless, open oceans and coastal ecosystems constitute very importance sources of ecosystem services and NPP (Costanza et al., 1997). While national ecological balances might change when ocean productivity is incorporated into natural production, humans are dramatically impacting the ability of ocean ecosystems to perform critical ecosystem services due to climate change, unrelenting pollution, and over-fishing. It is not unreasonable to foresee diminishing natural production from these over-exploited ocean resources.

Another area of concern is that NPP might change dramatically as a result of droughts, flooding, and severe storms associated with climate change (Krugman, 2010). These impacts could have significant impacts on local and regional ecosystems. It is certainly not beyond the realm of possibility that many countries could see dramatic reductions in NPP and slide deeper into ecological debt. For a world operating at full capacity, that could irreparably damage the ecosystems upon which all human beings rely.

A serious challenge to those of us studying issues of sustainability is understanding how ecological sustainability has changed (and will continue to change) in time and space. Coming to understand the complex ecological processes that take place within a cubic meter of rainforest is a monumental challenge unto itself (let alone trying to communicate those processes and their importance to the public). Despite the oversimplifications inherent in this approach to the global mapping of ecological sustainability we believe it is nonetheless useful, comprehensible, rhetorically powerful, and scientifically valid. We now have the capability to map ISA and NPP at moderate spatial resolution (1 km^2) on at least an annual basis if not more frequently. We hope future studies of sustainability will utilize these capabilities to inform our understanding of the spatio-temporal dynamics of ecological sustainability.

We hope this work is consilient with some of the spirit of the report on The Economics of Ecosystems and Biodiversity (TEEB) whose lead author eloquently described fundamental problems with the dominant neo-classical economic paradigm through which so much policy is based:

> "we are trying to navigate uncharted and turbulent waters with an old and defective economic compass and that this was affecting our ability to forge a sustainable economy in harmony with nature." (Sukhdev, 2009)

Specifically, this work will hopefully inform both policy makers and the public as to the nature, magnitude, potential dollar value, and spatial patterns of human impacts on the environment. The TEEB argues that the natural world provides services that have enormous economic value that is generally ignored. We hope this metric informs attempts to improve indicators and accounting systems for understanding the spatial and temporal variation dynamics of natural capital.

5. Conclusion

This study has presented a new method for the monetization of natural capital and human impact on supporting ecosystems. It is a step towards a much needed 'ecological accounting' at the global scale Global Footprint Network, 2006; Wackernagel et al., 2002). This spatially-explicit analysis assumes that we are operating our global economy at full capacity relative to ecosystem services; however, this may not be the case. Indeed, countries in an eco-deficit are already stretched beyond their national means. Increasing consumption and growing populations are also drawing down stocks of non-renewable minerals and fossil fuels. It is more likely that the current level of global economic activity exceeds sustainable limits.

This ecological accounting data set was found not to correlate highly with poverty. However, this may be (in whole or in part) due to the fact that both areas of high NPP and areas of low NPP correspond with areas of relatively high poverty. National-level poverty is associated with both abundant natural production and scarce natural production. In the former scenario, other countries and trans-national corporations are likely benefiting disproportionately from high natural production in the tropics. The ecological balances were found to have a high correlation with Ecological Deficit metrics established by the Global Footprint Network. Given the amount of data needed to generate Ecological Deficit numbers, and the fact that data are not available for some countries, this simple metric for ecological accounting may be a useful supplement to Ecological Deficit data.

The degree or intensity of sustainable and unsustainable behavior varies across the surface of the earth. This paper presents a preliminary attempt at capturing spatial variation in ecological sustainability. Aggregation of this relatively simple representation of biophysical sustainability to national levels correlates strongly with the sophisticated nationally explicit Ecological Deficit metric developed by Wackernagel and Rees, 1996. While we do not expect these monetized Ecological Balance figures to be incorporated into policy any time soon, we do believe the national dollar values derived from this spatially explicit Ecological Balance sheet suggest a starting point for discussions of the dollar values and costs of both sustainable and non-sustainable behavior on the part of the nations of the world.

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