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SPECIAL ISSUE: The Dynamics and Value of Ecosystem Services: Integrating Economic and Ecological Perspectives

Global estimates of market and non-market values derived from nighttime satellite imagery, land cover, and ecosystem service valuation

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Abstract

We estimated global marketed and non-marketed economic value from two classified satellite images with global coverage at 1 km^2 resolution. GDP (a measure of marketed economic output) is correlated with the amount of light energy (LE) emitted by that nation as measured by nighttime satellite images. LE emitted is more spatially explicit than whole country GDP, may (for some nations or regions) be a more accurate indicator of economic activity than GDP itself, can be directly observed, and can be easily updated on an annual basis. As far as we know, this is the first global map of estimated economic activity produced at this high spatial resolution (1 km^2). Ecosystem services product (ESP) is an important type of non-marketed value. ESP at 1 km^2 resolution was estimated using the IGBP land-cover dataset and unit ecosystem service values estimated by Costanza et al. [Valuing Ecosystem Services with Efficiency, Fairness and Sustainability as Goals. *Nature's Services*, Island Press, Washington DC, pp. 49–70]. The sum of these two (GDP + ESP) = SEP is a measure of the subtotal ecological–economic product (marketed plus a significant portion of the non-marketed). The ratio: (ESP/SEP) × 100 = %ESP is a measure of proportion of the SEP from ecosystem services. Both SEP and %ESP were calculated and mapped for each 1 km^2 pixel on the earth's surface, and aggregated by country. Results show the detailed spatial patterns of GDP, ESP, and SEP (also available at: http://www.du.edu/ ~ psutton/esiindexisee/EcolEconESI.htm). Globally, while GDP is concentrated in the northern industrialized countries, ESP is concentrated in tropical regions and in wetlands and other coastal systems. %ESP ranges from 1% for Belgium and Luxembourg to 3% for the Netherlands, 18% for India, 22% for the United States, 49% for Costa Rica, 57% for Chile, 73% for Brazil, and 92% for Russia. While GDP per capita has the usual northern industrialized countries at the top of the list, SEP per capita shows a quite different picture, with a mixture of countries with either high GDP/capita, high ESP/capita, or a combination near the top of the list. Finally, we compare our results with two other indices: (1) The *2001 Environmental Sustainability Index* (ESI) derived as an

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initiative of the Global Leaders of Tomorrow Environment Task Force, World Economic Forum, and (2) *Ecological Footprints of Nations: How much Nature do they use? How much Nature do they have?* developed by Mathis Wackernagel and others. While both of these indices purport to measure sustainability, the ESI is actually mainly a measure of economic activity (and is correlated with GDP), while the Eco-Footprint index is a measure of environmental impact. The related eco-deficit (national ecological capacity minus national footprint) correlates well with %ESP.

Keywords: Satellite images; Ecosystem service valuation; Satellite imagery

1. Introduction

Economic activity is fundamentally a spatial phenomenon. Both traditional marketed economic activities (like manufacturing, sales, and final consumption) and 'non-marketed' ecosystem services occur at specific spatial locations and are associated with specific natural, agricultural, or urban ecosystems. A necessary step toward better understanding these activities and services is to map their spatial patterns. That is what we have tried to do in this paper, at both the global and national level.

Various measures of 'economic activity' and environmental quality are also important as 'indicators' for policy decisions. Key questions here revolve around exactly what the indicators measure. Gross Domestic Product (GDP) is the most popular indicator of economic performance. But GDP measures only marketed economic *activity* or gross income (Costanza et al., 2001). It was never intended as a measure of economic welfare, and it functions very poorly as a welfare measure. Yet it is inappropriately used as a national welfare measure in far too many circumstances.

What are the problems with GDP as a welfare measure? First, lumping all activity or income together does not separate desirable, welfare enhancing activity from undesirable welfare reducing activity. For example, an oil spill increases GDP because someone has to clean it up, but it obviously detracts from welfare. From the perspective of GDP, more crime, more sickness, more war, more pollution, more fires, storms, and pestilence are all good things, since they can increase marketed activity in the economy. Second, GDP leaves out many things that currently *do* enhance welfare but are outside the market. The unpaid work of mothers caring for their own children at home doesn't show up in GDP, but if they decide to work outside the home to pay for child care, GDP suddenly increases. The non-marketed services of nature in providing clean air and water, food and natural resources do not show up in GDP, but if those services are damaged and we have to pay to fix or replace them, then GDP suddenly increases. Third, GDP takes no account of the distribution of income among individuals. But it is well known that an additional $1 worth of income produces more *welfare* if one is poor rather than rich (Daly and Cobb, 1989).

In this paper we look at the spatial patterns of conventional GDP and also at the value of non-marketed ecosystem services that are not currently included in GDP (de Groot et al., 2002; Costanza et al., 1997a,b). We do not address the other important shortcomings of GDP (including distribution, unpaid domestic labor, pollution, etc.)—leaving those for future work. In this paper we focus on the subtotal of economic value represented by the sum of conventional marketed economic goods and services (as measured by GDP) and non-marketed ecosystem goods and services. A list of these ecosystem services and their approximate dollar values for a range of ecosystems are given in Costanza et al. (1997a,b). A more detailed description of these services and their links to ecosystem functions is given in de Groot et al. (2002).

Other indicators at the global and national level are also proliferating. In particular, there are many new proposed indicators of 'sustainability'. We contend that none of these proposed indicators of sustainability actually measure sustainability. They are generally indicators of economic and/or environmental quality or stress in the present, and the link is tenuous at best as to whether or not these indices say anything at all about the sustainability of these patterns over time.

For example, the 'Ecological Footprint' (EF) and the '2001 Environmental Sustainability Index' (ESI) are two distinct, independent attempts specifically aimed at assessing sustainability (Wackernagel et al., 1997; Samuel-Johnson and Esty, 2001). The EF is a composite index involving many variables, which focus on the nature and productivity of land resources, variability of human consumption patterns, and the energy accounting of each nation's international trade. The land variables focus on areal extent, biological productivity, and waste absorption capacity. The consumption variables characterize and account for the differing ecological impact of human consumption throughout the nations of the world. Finally, the ecological footprint index tries to capture the separation of production and consumption by looking at the import and export goods of each nation to see who is actually consuming the energy associated with manufacturing, agriculture, etc. (Chisolm, 1990). Wackernagel's index calculated the following measures for 52 nations of the world: Total Ecological Footprint (a measure of impact), Available Ecological Capacity, and Ecological Deficit (ED, the difference between the two) (Wackernagel and Rees, 1996).

The EF is clearly a measure of environmental impact, not sustainability. The ED is usually interpreted as a measure of sustainability—the higher the ED the lower the sustainability. But while the ED clearly shows whether ecosystem services are being imported across country boundaries, it says nothing (necessarily) about the sustainability of that pattern of imports, or about the capacity of ecosystems to sustain these flows (Folke et al., 1996).

The 2001 ESI was developed as an initiative of the Global Leaders of Tomorrow Environment Task Force of the World Economic Forum. The Yale Center for Environmental Law and Policy (YCELP) and the Center for International Earth Science Information Network (CIESIN) contributed to the development of this index. The ESI attempts to develop a '*transparent*, *interactive process that draws on rigorous statistical*, *environmental*, *and analytic expertise to quantify environmental sustainability*'. According to the main report of the ESI document, the key results are: (1) Environmental Sustainability can be measured. (2) The Index creates benchmarks of environmental conditions that can influence decision-making. (3) Serious 'data gaps' for many nations of the world should be filled. (4) Economic conditions affect, but do not determine, environmental conditions; and, policy regarding these conditions are separate choices. The ESI is derived by averaging five key 'core' components (parenthetical key: *Component [# of Indicators]*: Environmental Systems [5], Reducing Stresses [5], Reducing Human Vulnerability [2], Social and Institutional Capacity [7], and Global Stewardship [3]). The 'Indicator' variables that constitute the five key components are themselves derived from 67 specifically measurable and nationally aggregate variables. Examples of a few of the 67 fundamental variables are: 'urban SO_2 concentration', 'total fertility rate', 'scientific and technical articles per million of population', and 'number of memberships in environmental inter-governmental organizations'. One of the variables used in the ESI that measured anthropogenic impact on the land was in fact derived from a composite nighttime satellite image and a similar global land cover dataset (Elvidge et al., 1995). How these 67 variables should be weighted is a complex question, which the ESI report reasonably avoids. The 'weighting' question is undoubtedly an element of the 'interactive' nature of developing indices for which there will be a consensus. One notable result of the arithmetic involved in generating the ESI is the fact that the aggregate national numbers correlate strongly with nationally aggregate measures of GDP/Capita (more on this later).

The point is that there is a strong need for defensible, measurable indicators of economic performance and environmental quality and these indicators do not yet exist. We propose to remedy this deficit in this paper. We also compare our results with the two existing indicators mentioned above (ED and ESI), noting that neither of them is actually measuring sustainability. Sustainability is much more difficult to assess and requires (at minimum) a dynamic modeling approach to even begin to frame the appropriate questions (c.f. Boumans et al., 2002). It also requires a shift in thinking from a view of nature as stable and in equilibrium to one of complex and adaptive social–ecological systems (Costanza et al., 1993).

2. Data and methods

The indices described in this paper use two datasets to measure the ‘Market’ and ‘Non-Market’ economy of nations. The proxy measure of ‘Market’ economy is the amount of LE emitted from each nation as measured by a nighttime satellite image of the world. Nighttime imagery has been shown to be a strong proxy measure of GDP in earlier studies (Elvidge et al., 1997). The proxy measure of ‘Non-Market’ economy is a measure of the total value of the ecosystem services of the lands and waters of each nation as measured by a global land-cover dataset (Belward, 1996) and the corresponding ecosystem service value of the different ecosystem types (Costanza et al., 1997a,b). Some advantages of this particular measure are that it can be updated in time with subsequent satellite measurements, has widespread global coverage, can be calculated at a 1 km^2 spatial resolution, and is intuitively clear and comprehensible.

The indices are referred to from here as: (GDP 1995) (which is compared across countries using purchasing power parity rather than official currency exchange rates), ecosystem service product (ESP), subtotal ecological–economic product (SEP = ESP + GDP), SEP/capita (= SEP/country population), and percent ecosystem service product (%ESP = 100 × (ESP/SEP)). We use the term ‘Subtotal’ to indicate that the sum of these two components does not add up to the total ecological–economic product, but represents a significant subtotal of that value. These indices are calculated for each square kilometer of land surface and aggregated for each nation of the world.

2.1. Measuring ‘market’ and ‘non-market’ economies using satellite imagery

The nighttime satellite image is a global dataset derived from mosaicing hundreds of orbits of the Defense Meteorological Satellite Program’s Operational Linescan System (DMSP OLS). This image has been screened for clouds and ephemeral lights such as lightning, forest fires, gas flares, and lantern fishing (Elvidge et al., 1998). Studies of this imagery have shown it to correspond with the extent of urban land cover, population density, energy consumption, greenhouse gas emissions and other socio-economic parameters (Elvidge et al., 1997; Imhoff et al., 1997; Sutton et al., 1997; Doll et al., 2000). The image is radiance calibrated so an integration of the values of the pixels over the land of a nation is a measure of total LE. This global image of radiance calibrated nighttime lights is used to create a 1 km^2 resolution image of marketed economic activity globally. At the nationally aggregate level the correlation between the Ln(LE) and Ln(GDP) is $R^2 = 0.74$. We did not feel that the strength of this correlation was significantly strong to use the GDP estimated from the LE when constructing the fine resolution map of economic activity. Consequently this was accomplished by creating nationally specific ratios of GDP and LE for each nation of the world and applying these relationships to the global nighttime satellite image to get an image of $GDP per year km^2. One means of assessing the validity of this method of spatial dissaggregation of economic activity is to look at the 1995 Gross State Product (GSP) of the conterminous US states and regressing GSP with the measured LE from each state. The following relationship proved to be quite strong:

$$\text{Ln(Gross State Product)} = \alpha + \beta 1 \times \text{Ln(LE)}$$

This produced an α of approximately -4.25, a $\beta 1$ of 1.05, with an $R^2 = 0.86$ (Fig. 1). Future work to improve the models to estimate economic activity across countries from the nighttime imagery might improve this relationship. The fine spatial resolution image of economic activity was derived from 1995 and 1996 orbits of the DMSP platform (Fig. 2).

The dataset used to measure 'Non-Market' economy was a global land-cover dataset developed by the United States Geological Survey and available on the web (http:/edcdaac.usgs.gov/glcc/glcc.html). The International Geosphere Biosphere Program (IGBP) participated in developing a version of this dataset with seventeen land-cover classes representing the major biomes of the world. These classes were matched to the corresponding ecosystem service values calculated by Costanza et al. (1997a,b) to estimate the total annual value of each nation's ecosystem services (Table 1). In this case 'Non-Market' economy represents the economic value of ecosystem services rather than the 'informal' part of the economy of human commerce. Fig. 3 shows the resulting map at 1 km^2 of ESP for the terrestrial component of ecosystem services.

Marine ecosystems have been estimated to account for about two thirds of the value of the earth's ecosystem services (Costanza et al., 1997a,b). Incorporating these values into this analysis would have most reasonably been accomplished using a dataset of the Exclusive Economic Zone boundaries of the world's nations (Solutions, 2000). Unfortunately, data cost issues precluded the inclusion of this dataset into this analysis. In order to get a reasonable sense of the proportion of each nation's economic activity provided by ecosystem services, a simplifying calculation was performed to include marine resources. The total value of a nation's ecosystem services is the sum of its terrestrial and marine services. The value of each nation's marine services was approximated by attributing to each nation a fraction of the world's marine resources based on that country's fraction of the world's land area. This approximation admittedly underestimates the ecosystem services available to small island nations and overestimates the ecosystem services available to large land-locked nations. We hope to improve this situation in the next iteration as better data become available.

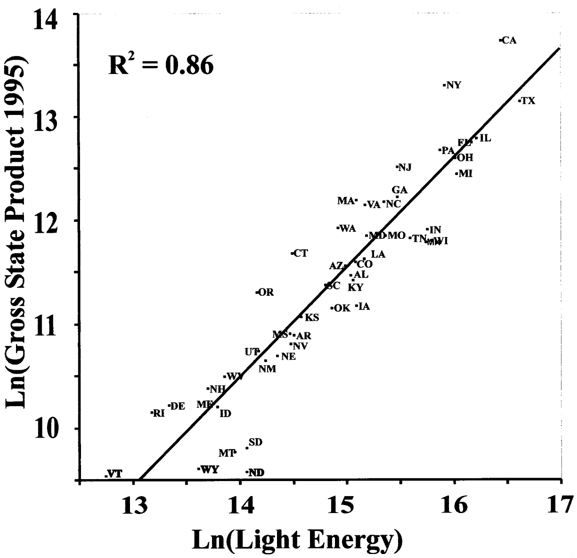


Fig. 1. Ln(GSP 'actual') vs. Ln(GSP 'predicted') for conterminous US.

In addition, the total value of terrestrial ecosystem services when calculated with the 1 km^2 resolution IGBP land cover dataset did not agree exactly with the figures published by Costanza et al. (1997a,b). This is undoubtedly influenced by questions associated with how the total value of ecosystem services are influenced by the spatial scale of measurement of land cover (cf. Konarska et al., 2002). For example, wetlands are very high-valued ecosystems, but they are also fairly small in size and their total global area is badly underestimated at 1 km^2 resolution. A 'scaling' correction was applied to this measurement in order to make the numbers correspond more closely with the previous figures. A factor of 1.5 and 2.0 were applied to the areal extent of water and wetlands, respectively. The scale factors of 1.5 and 2.0 used for the areal extent of water and wetlands made their numbers comparable to those in the figures published by Costanza et al. (1997a,b). This increased the total value of global terrestrial ecosystem services from \$9.3 to \$12.8 trillion. These scale factors result in the \$12.8 trillion terrestrial value being comparable to the 1997 total terrestrial value of \$12.3 trillion.

Figs. 5–8 are nationally aggregated maps of ESP (including the marine component and the scale adjustment mentioned above), SEP, SEP/capita, and %ESP, respectively. Table 2 is a summary table listing all data at the country level. All the figures and datasets associated with this analy-

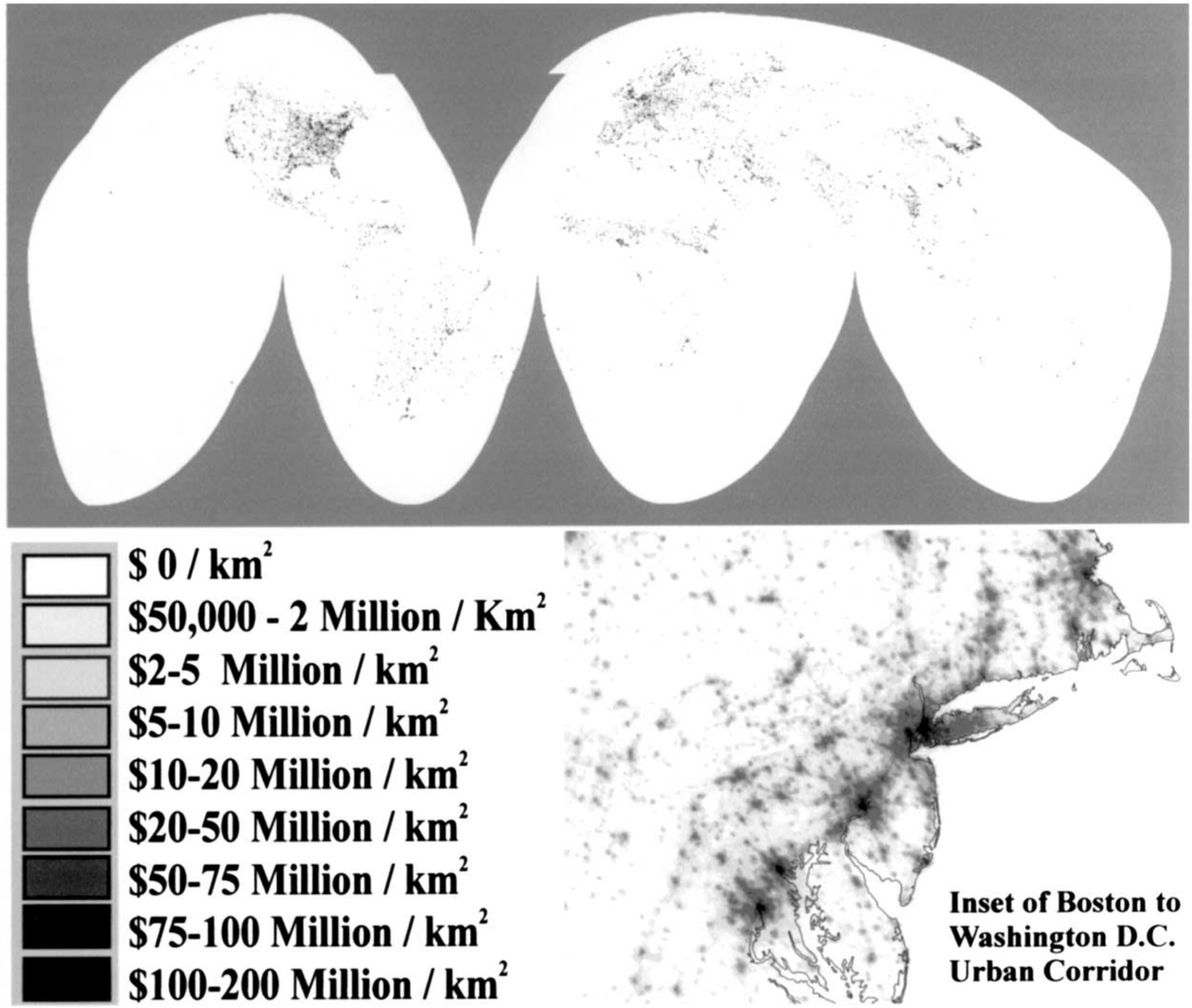


Fig. 2. 'Market' economy (GDP) as measured by Night Image Proxy at 1 km^2 (w/ inset Boston-DC).

sis can be examined and/or downloaded from the web at the following website: http://www.du.edu/~psutton/esiindexisee/EcolEconESI.htm.

Generation of global land-cover maps is not as easy as generation of global night-light products. However, a strong correlation between the total value of ecosystem services and primary productivity has been documented by Costanza et al. (1998) Consequently, global maps of net primary productivity (Field et al., 1998) might be used instead of land-cover data and might be easier to update on a more frequent basis than land use. This may be a more appropriate proxy for the value of ecosystem services. We leave this for future work.

3. Results

Figs. 2–8 represent a new and more comprehensive picture of marketed and non-marketed economic value at a global scale. The 1 km^2 resolution of the basic data sets and Figs. 2–4 allow for an unprecedented view of how these values are spatially distributed around the planet.

Fig. 2 is the highest spatial resolution estimate of marketed economic activity (GDP) we know of to date. The concentration of GDP in the US, the EU, and Japan is obvious from inspection of Fig. 2. The detailed inset in Fig. 2 shows a typical pattern of urban and suburban development where this activity is concentrated.

Fig. 3 is a much more spatially detailed version of the map of ecosystem service values that appeared in Costanza et al. (1997a,b), sans the marine component. The concentration of these values in tropical areas and wetlands is apparent, along with the broad distribution of services from forests and grasslands.

Fig. 4 represents the first attempt to map the subtotal of GDP plus ESP (= SEP). This interesting composite shows the hot spots arising from both GDP (US, EU, Japan) and ESP (tropics, wetlands, etc.) and is a closer approximation to the total value of goods and services produced annually that support the human economy.

Figs. 5–8 are the same data nationally aggregated. All the data from which these maps were derived, plus additional related data, are shown in Table 2.

Fig. 5 is ESP at the national scale, including an estimate of the marine component and adjusted for scaling problems (see above). The size of the country obviously has a big influence on the results viewed in this way. All the countries with large land areas (US, Canada, Russia, China, Brazil, Australia) show up with high ESP's.

Fig. 6 shows SEP at the national scale, again emphasizing the large countries, but also adding the small countries with large GDP's (Japan, EU countries) to the upper ranks. Table 7 shows SEP/capita, which pinpoints a few countries with relatively high SEP's and relatively low populations (Canada, Greenland, Suriname, Gabon) as topping the list, while countries with moderate SEP's and very high populations (China, India) are at the bottom. What does this say about the 'real' income of people when both marketed and non-marketed services are included?

Fig. 8 shows %ESP at the national scale. Russia, Canada, and much of Africa and South America top this list (see also Table 2). The nations with the highest %ESP were: Equatorial Guinea (99%), Guyana (98%), Democratic Republic of Congo (Zaire) (98%), Central African Republic (97%), Mongolia (97%), and numerous small island nations and protectorates. The nations with the lowest %ESP scores were: Hong Kong (0%), Belgium (1%), Singapore (1%), and Luxembourg (1%). What does this say about conventional ideas concerning 'development'?

Table 1
IGBP to nature biome $ conversion table

IGBP class	Nature paper interpretation	Value ($/ha)	IGBPcode
Evergreen needleleaf forest	Temperate forest	302	1
Evergreen broadleaf forest	Tropical forest	2007	2
Deciduous needleleaf forest	Temperate forest	302	3
Deciduous broadleaf forest	Temperate forest	302	4
Mixed forest	25% tropical, 75% temperate	728.25	5
Closed shrub lands	Grass/range lands	232	6
Open shrub lands	Grass/range lands	232	7
Woody savannas	50% temperate forest, 50% grass/range lands	267	8
Savannas	Grass/range lands	232	9
Grasslands	Grass/range lands	232	10
Permanent wetlands	50% tidal marsh/mangrove, 50% swamp/flood plain	14785	11
Croplands	Cropland	92	12
Urban	Urban	N/A	13
Cropland natural vegetation mosaic	50% cropland, 50% grassland/range land	162	14
Snow and ice	Ice/rock	N/A	15
Barren or sparsely vegetated	Desert	N/A	16
Water bodies	Lakes/rivers	8498	17

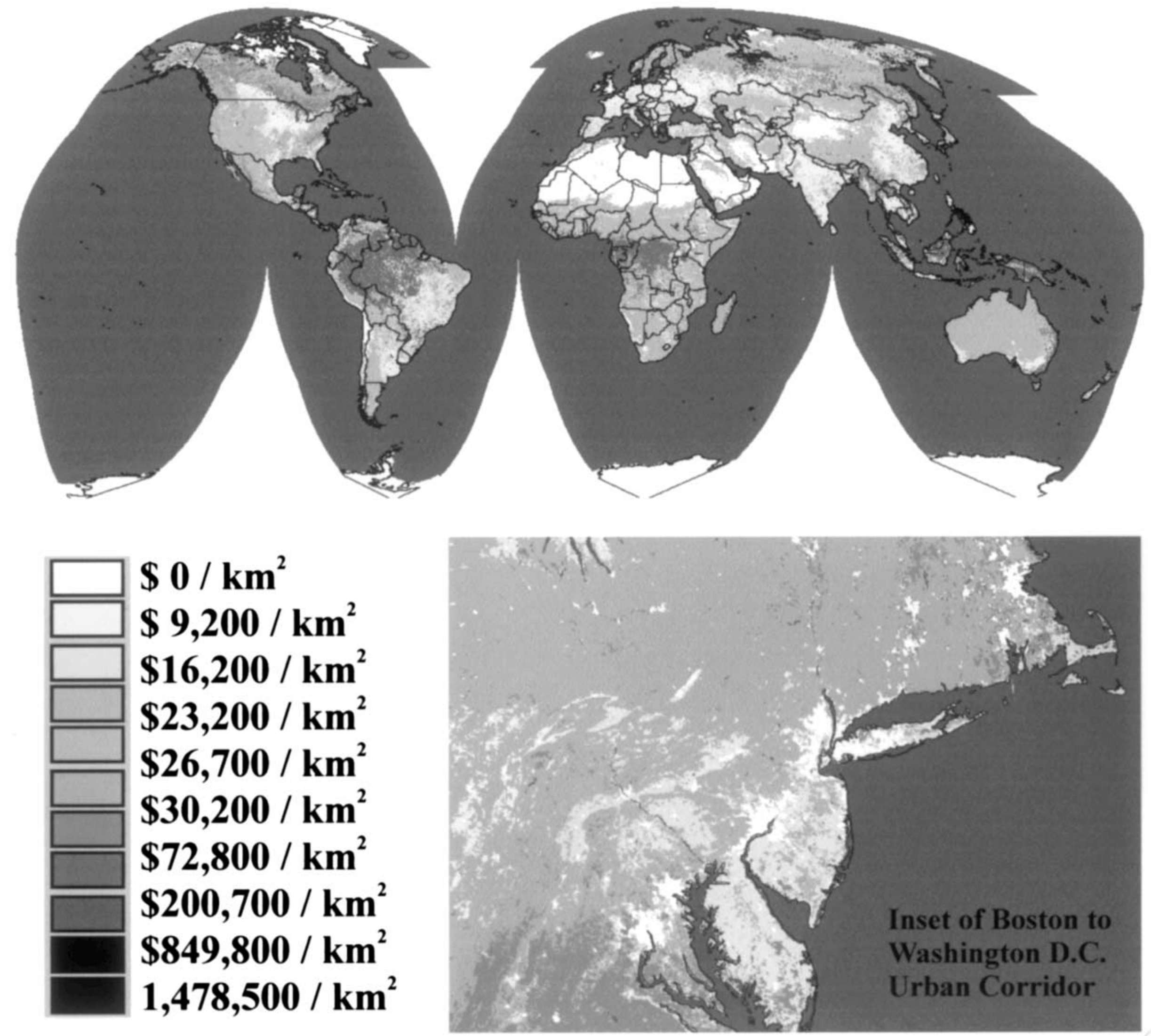


Fig. 3. 'Non-Market' or Ecosystem Service Product (ESP) at 1 km^2 resolution (w/ inset Boston, DC).

3.1. Comparing the %ESP index to the ESI and ED

A correlation matrix of various parameters was created for the 49 nations that had a ESI and an ED figure from Wackernagel (Table 3). The %ESP index correlated negatively with both population density (−0.25) and GDP/Capita (−0.16). In contrast, the ESI correlated very strongly with GDP/Capita (0.73). The Ecological Footprint data of Wackernagel and others was posted on the web for 1993 and 1997 calculations. The 1997 data for the 52 nations reported was used here. The ESI was produced as a pilot measure in 2000 and as a more substantial measure in 2001 (Samuel-Johnson, 2000). We used the 2001 data for 122 nations. In addition, the ESI published within its report a measure of Ecological Deficit measured along the lines of Wackernagel's Ecological Footprint methods for 118 nations. The

Table 2
all indices used in this study aggregated by country

Country	Fips Code	Population (1000's) (1995)	PPP of GDP (1995) (Billions)	PPP per Capita	Total Light Energy from DMSP OLS	PPP ($Billions) by DMSP Proxy	ESP ($Billions) Land	ESP ($Billions) Marine	ESP ($Billions) Total(Land + Marine)	Rank ESP	SEP ($Billions) Sum of PPP and ESP	Rank SEP	%ESP	Rank %ESP	SEP/Capita	Rank SEP/Capita	GDP per Energy Use
Afghanistan	AF	22132	12.8	578	13052	2	14.132	24.032	38.164	81	50.964	107	75	162	2303	217	
Albania	AL	3405	4.1	1204	31330	4	1.894	3.221	5.114	147	9.214	174	56	128	2706	207	2.4
Algeria	AG	29830	108.7	3644	2957265	171	11.007	18.719	29.726	91	138.426	63	21	79	4640	189	2.6
American Samoa	AQ	61	1.59	26000	1734	0	0.04	0.067	0.107	220	1.693	203	6	39	27749	63	
Andorra	AN	68	1.12	16500	22992	3	0.01	0.017	0.027	230	1.149	210	2	19	16894	101	
Angola	AO	11569	47.43	4100	213609	20	94.154	219.371	313.525	14	360.958	29	87	185	31200	58	7
Anguilla	AV	7	0.52	74000	1675	0	0.118	0.201	0.319	201	0.837	217	38	108	119602	20	
Antarctica	AY	0	0		0		52.27	88.888	141.158	31	141.158	61	100	226			
Antigua and Barbuda	AC	66	4.88	74000	5438	1	0.215	0.366	0.581	188	5.465	182	11	52	82810	30	2.9
Argentina	AR	35558	278.5	7832	5169657	268	106.061	180.362	286.423	18	564.923	19	51	122	15887	104	2.7
Armenia	AM	3790	9.1	2401	44429	6	2.772	4.714	7.486	139	16.586	154	45	115	4376	191	1.4
Aruba	AA	67	5.5	82100	18627	3	0.025	0.042	0.066	225	5.567	181	1	11	83090	29	
Australia	AS	18700	405.4	21679	2762579	161	304.911	518.515	823.425	7	1228.825	11	67	146	65713	34	2.6
Austria	AU	8077	152	18819	896125	65	4.112	6.992	11.104	120	163.104	53	7	42	20194	84	5.4
Azerbaijan	AJ	7582	11.5	1517	188929	18	3.865	6.572	10.437	124	21.937	144	48	116	2893	205	0.2
Bahamas	BF	285	4.8	16842	42064	5	13.747	23.377	37.124	82	41.924	121	89	189	147103	13	
Bahrain	BA	620	7.3	11774	121840	13	0.045	0.077	0.122	218	7.422	178	2	13	11971	127	0.8
Bangladesh	BG	122219	144.5	1182	261273	24	29.529	50.216	79.745	52	224.245	46	36	105	1835	222	3.1
Barbados	BB	265	2.5	9434	22123	3	0.076	0.129	0.205	211	2.705	194	8	44	10206	134	4.2
Belgium	BE	10162	197	19386	1973768	123	0.408	0.694	1.101	175	198.101	48	1	5	19494	90	3.2
Belize	BH	224	0.6	2679	12633	2	4.082	6.941	11.023	121	11.623	165	95	215	51890	42	5.1
Benin	BN	5946	7.6	1278	249046	23	5.121	8.709	13.83	114	21.43	145	65	142	3604	199	18
Bermuda	BD	61	1.7	27869	2092	0	0.041	0.071	0.112	219	1.812	202	6	38	29706	60	
Bhutan	BT	842	1.3	1544	1428	0	1.013	1.723	2.736	158	4.036	188	68	148	4793	188	16.9
Bolivia	BL	7810	20	2561	704642	53	112.65	191.567	304.217	15	324.217	31	94	211	41513	51	2.1
Bosnia and Herzegovina	BK	3600	1	278	99409	11	1.25	2.126	3.376	153	4.376	187	77	164	1215	227	
Botswana	BC	1501	4.5	2998	37710	5	23.506	39.973	63.48	62	67.98	95	93	210	45290	47	4.7
Bouvet Island	BV	0	0		0		0.017	0.028	0.045	226	0.045	232	100	234			
Brazil	BR	160343	976.8	6092	12089302	533	956.423	1626.44	2582.86	3	3559.661	5	73	159	22200	75	2.8
British Virgin Islands	VI	20	0.28	14286	1931	0	0.25	0.425	0.676	184	0.956	216	71	157	48760	44	
Brunei	BX	298	4.6	15436	69453	8	0.734	1.249	1.983	166	6.583	179	30	97	22091	77	1
Bulgaria	BU	8321	43.2	5192	261355	24	2.68	4.557	7.237	140	50.437	108	14	62	6061	169	1
Burkina Faso	UV	10891	7.4	679	295894	26	6.199	10.542	16.742	110	24.142	140	69	153	2217	219	16
Burundi	BY	6052	4	661	4252	1	3.607	6.133	9.74	125	13.74	160	71	158	2270	218	8.3
Byelarus	BO	10270	49.2	4791	605994	47	4.786	8.139	12.925	115	62.125	100	21	78	6049	170	
Cambodia	CB	11164	7	627	45866	6	18.273	31.075	49.348	71	56.348	104	88	186	5047	183	2.4
Cameroon	CM	13937	16.5	1184	1129714	78	53.527	91.025	144.552	29	161.052	55	90	192	11556	129	6.9
Canada	CA	30142	694	23024	23655338	919	2077.97	3533.68	5611.65	2	6305.649	3	89	191	209198	8	2
Cape Verde	CV	390	0.4	1026	3152	1	0.139	0.236	0.375	197	0.775	220	48	119	1988	221	2.1
Cayman Islands	CJ	36	8.82	245000	8640	2	0.187	0.318	0.506	190	9.326	173	5	35	259050	6	
Central African Republic	CT	3342	2.5	748	1900538	119	28.465	48.407	76.872	53	79.372	87	97	222	23750	69	
Chad	CD	6984	3.3	473	669420	51	19.732	33.555	53.287	67	56.587	103	94	212	8102	149	10.9
Chile	CI	12500	113.2	9056	1431450	95	56.03	95.281	151.311	27	264.511	37	57	130	21161	81	2.3
China	CH	1236693	3500	2830	12296388	541	359.894	612.016	971.91	6	4471.91	4	22	80	3616	198	0.7
Christmas Island	KT	3		0	408	0	0.106	0.18	0.285	205	0.285	228	100	230	111398	23	
Colombia	CO	37418	192.5	5145	1912255	120	158.61	269.724	428.334	10	620.834	16	69	152	16592	102	2.1
Comoros	CN	590	0.4	678	0		0.417	0.709	1.126	174	1.526	206	74	160	2587	210	11.8
Congo	CF	2583	7.7	2981	66464	8	53.196	90.462	143.658	30	151.358	60	95	216	58598	39	2.8
Cook Islands	CW	20	0.11	5685	98	0	0.171	0.29	0.461	193	0.573	223	80	171	29100	61	
Costa Rica	CS	3466	18.4	5309	246438	23	6.45	10.968	17.418	108	35.818	129	49	120	10334	133	3.4
Croatia	HR	4772	20.1	4212	374671	32	3.064	5.21	8.274	135	28.374	134	29	93	5946	172	
Cuba	CU	11068	14.7	1328	216858	21	21.572	36.685	58.257	64	72.957	93	80	170	6592	165	
Cyprus	CY	746	8.3	11126	134644	14	0.457	0.777	1.234	173	9.534	171	13	60	12780	117	2.8
Czech Republic	EZ	10314	106.2	10297	1788367	113	1.506	2.562	4.068	151	110.268	77	4	27	10691	132	0.8
Denmark	DA	5286	112.8	21339	785815	58	4.507	7.665	12.172	117	124.972	68	10	50	23642	70	5.5
Djibouti	DJ	634	0.5	789	1639	0	0.402	0.683	1.085	176	1.585	205	68	151	2500	211	
Dominica	DO	83	2.48	29900	831	0	0.067	0.115	0.182	213	2.664	195	7	43	32091	56	7.4
Dominican Republic	DR	8222	26.8	3260	272830	25	15.169	25.795	40.964	77	67.764	96	60	133	8242	148	2.5
Ecuador	EC	11999	44.6	3717	473140	39	26.464	45.002	71.466	56	116.066	75	62	135	9673	139	2.2
Egypt	EG	64792	171	2639	3334001	188	9.371	15.936	25.307	97	196.307	49	13	59	3030	203	
El Salvador	ES	5935	11.4	1921	157777	16	1.703	2.896	4.599	150	15.999	156	29	92	2696	208	2.6
Equatorial Guinea	EK	420	0.3	714	8685	2	9.383	15.956	25.339	98	25.639	138	99	225	61046	37	5.2
Eritrea	ER	3590	2	557	15169	2	2.813	4.784	7.597	137	9.597	170	79	167	2673	209	
Estonia	EN	1454	12.3	8459	262138	24	5.466	9.296	14.762	111	27.062	137	55	127	18612	96	0.7
Ethiopia	ET	58733	24.2	412	2594898	153	42.523	72.313	114.836	36	139.036	62	83	177	2367	213	6.9
Falkland Islands	FK	2	0.38	190000	520	0	1.093	1.859	2.952	156	3.332	190	89	190	1666174	2	
Faroe Islands	FO	45	7.2	160000	3599	1	0.685	1.164	1.849	169	9.049	176	20	76	201082	9	
Federated States of Micronesia	FM	112	0.9	8000	185	0	0.177	0.301	0.478	192	1.374	207	35	104	12267	121	
Fiji	FJ	826	4.7	5690	4619	1	1.755	2.985	4.74	148	9.44	172	50	121	11429	130	3.9
Finland	FI	5144	92.4	17963	4066823	221	61.185	104.048	165.232	24	257.632	38	64	141	50084	43	3
France	FR	58633	1173	20006	8928907	417	15.453	26.278	41.731	75	1214.731	12	3	25	20718	83	4.4
French Guiana	FG	159	9.54	60000	8260	1	16.265	27.659	43.924	72	53.464	106	82	176	336249	5	
French Polynesia	FP	226	15.82	70000	6249	1	0.952	1.619	2.571	159	18.391	152	14	61	81378	31	
Gabon	GB	1190	6	5042	138533	14	57.618	97.982	155.599	26	161.599	54	96	220	135798	16	5.5
Gambia	GA	1169	1.1	941	6452	1	2.997	5.096	8.092	136	9.192	175	88	188	7863	152	
Gaza Strip	GZ	1024	128	125000	23927	3	0.032	0.054	0.085	223	128.085	66	0	1	125083	18	
Georgia	GG	5411	6.2	1146	58739	7	3.2	5.441	8.641	134	14.841	157	58	131	2743	206	0.7
Germany	GM	82022	1452.2	17705	8339961	395	11.05	18.79	29.84	90	1482.04	9	2	17	18069	98	
Ghana	GH	18102	25.1	1387	508216	41	36.024	61.26	97.283	45	122.383	71	79	169	6761	163	4.4
Greece	GR	10522	101.7	9665	862580	63	9.262	15.75	25.012	99	126.712	67	20	75	12043	125	2.2
Greenland	GL	57	9.12	160000	2401	1	20.051	34.097	54.148	65	63.268	99	86	181	1109962	3	
Grenada	GJ	96	2.86	29800	1246	0	0.035	0.059	0.093	222	2.954	192	3	23	30773	59	6.9
Guadeloupe	GP	436	41.86	96000	50406	6	0.355	0.604	0.959	180	42.815	118	2	18	98199	26	
Guam	GQ	156	15.6	100000	45246	6	0.167	0.284	0.451	194	16.051	155	3	21	102891	24	
Guatemala	GT	11241	36.7	3265	176101	17	11.14	18.943	30.083	89	66.783	97	45	114	5941	173	4.3
Guernsey	GK	64	1.15	17969	3944	1	0.051	0.087	0.139	215	1.289	208	11	53	20138	85	
Guinea	GV	7495	6.5	867	1106264	77	13.357	22.714	36.071	84	42.571	119	85	180	5680	176	6.1
Guinea-Bissau	PU	1112	1	899	28636	4	7.219	12.275	19.494	104	20.494	147	95	217	18430	97	5.8

Table 2 (*Continued*)

Country	Fips Code	Population (1000's) (1995)	PPP of GDP (1995) (Billions)	PPP per Capita	Total Light Energy from DMSP OLS	PPP ($Billions) by DMSP Proxy	ESP ($Billions) Land	ESP ($Billions) Marine	ESP ($Billions) Total(Land + Marine)	Rank ESP	SEP ($Billions) Sum of PPP and ESP	Rank SEP	%ESP	Rank %ESP	SEP/Capita	Rank SEP/Capita	GDP per Energy Use
Guyana	GY	847	1.6	1889	13207	2	38.234	65.018	103.252	43	104.852	78	98	224	123793	19	1.5
Haiti	HA	6611	6.5	983	15891	2	11.804	20.074	31.878	88	38.378	125	83	178	5805	174	7.9
Heard & McDonald Island	HM	0	0		0		0.048	0.082	0.131	216	0.131	229	100	233			
Honduras	HO	5751	10.8	1878	129804	14	13.742	23.369	37.111	83	47.911	110	77	165	8331	147	4.4
Hong Kong	HK	6878	152.4	22158	203906	20	0.223	0.38	0.603	187	153.003	58	0	2	22245	74	5.3
Hungary	HU	10166	72.5	7132	1065209	75	3.232	13.675	16.908	109	89.408	82	19	71	8795	144	1
India	IN	969729	1408.7	1453	9744352	448	117.989	200.646	318.635	13	1727.335	7	18	69	1781	223	1.6
Indonesia	ID	204323	710.9	3479	1480227	97	287.517	488.934	776.451	8	1487.351	8	52	125	7279	161	1.8
Iran	IR	67540	323.5	4790	6256227	313	35.56	60.472	96.032	47	419.532	26	23	83	6212	168	
Iraq	IZ	21177	41.1	1941	1359677	91	14.222	24.185	38.408	79	79.508	85	48	118	3754	196	
Ireland	EI	3609	54.6	15129	308431	27	8.325	14.157	22.481	101	77.081	90	29	94	21358	80	3.9
Israel	IS	5838	80.1	13720	1052796	74	1.059	1.802	2.861	157	82.961	83	3	26	14210	111	3.7
Italy	IT	57429	1088.6	18956	7558506	365	15.694	26.688	42.382	74	1130.982	13	4	28	19694	89	5.5
Ivory Coast	IV	14986	21.9	1461	551521	44	36.492	62.056	98.548	44	120.448	73	82	174	8037	150	
Jamaica	JM	2576	8.2	3183	140398	14	2.073	3.526	5.599	144	13.799	159	41	112	5357	180	1.5
Jan Mayen	JN	0	0		0		0.227	0.386	0.613	186	0.613	221	100	232			
Japan	JA	126054	2679.2	21254	13039189	567	40.945	69.63	110.575	40	2789.775	6	4	29	22132	76	6.2
Jersey	JE	89	2.2	24719	5071	1	0.037	0.063	0.1	221	2.3	198	4	31	25840	65	
Johnston Atoll	JQ	0	0		89	0	0.001	0.002	0.003	235	0.003	237	100	237			
Jordan	JO	4448	19.3	4339	339273	30	1.713	2.914	4.627	149	23.927	142	19	74	5379	179	1.5
Kazakhstan	KZ	16433	46.9	2854	1382484	92	157.461	267.769	425.229	11	472.129	25	90	193	28731	62	
Kenya	KE	28803	36.8	1278	122040	13	31.541	53.636	85.177	50	121.977	72	70	155	4235	193	3.3
Kiribati	KR	88	0.07	841	0		0.373	0.635	1.009	179	1.083	211	93	208	12302	120	3.8
Kuwait	KU	1809	30.8	17026	1191126	82	0.569	0.968	1.538	170	32.338	131	5	32	17876	100	2
Kyrgyzstan	KG	4606	5.4	1172	150765	15	14.178	24.11	38.288	80	43.688	115	88	187	9485	141	
Laos	LA	5117	5.2	1016	1158993	80	27.042	45.986	73.027	55	78.227	88	93	209	15288	107	
Latvia	LG	2457	14.7	5983	209368	20	3.489	5.933	9.422	128	24.122	141	39	110	9818	138	1.2
Lebanon	LE	3859	18.3	4742	275688	25	0.493	0.838	1.33	171	19.63	149	7	41	5087	182	
Lesotho	LT	2008	2.8	1394	11748	2	0.694	1.18	1.874	168	4.674	185	40	111	2328	215	
Liberia	LI	2257	2.3	1019	323	0	15.229	25.897	41.125	76	43.425	116	95	214	19240	92	
Libya	LY	5648	32.9	5825	1729622	110	3.882	6.601	10.482	123	43.382	117	24	88	7681	154	
Liechtenstein	LS	31	0.6	19355	4982	1	0.004	0.007	0.011	232	0.611	222	2	14	19710	88	
Lithuania	LH	3702	13.3	3593	280188	25	2.613	4.443	7.055	141	20.355	148	35	103	5498	177	0.8
Luxembourg	LU	422	10	23697	165685	17	0.028	0.047	0.074	224	10.074	168	1	8	23873	67	2.3
Macedonia	MK	2121	1.9	896	87697	10	1.133	1.927	3.06	154	4.96	184	62	137	2339	214	
Madagascar	MA	14062	11.4	811	24642	4	41.871	71.204	113.076	38	124.476	69	91	198	8852	143	5.6
Malawi	MI	9609	6.9	718	56375	7	31.148	52.968	84.116	51	91.016	81	92	203	9472	142	3.4
Malaysia	MY	21018	193.6	9211	1040445	73	42.477	72.234	114.711	37	308.311	34	37	107	14669	109	1.7
Maldives	MV		0.4		0		1.978	3.364	5.343	146	5.743	180	93	207			4.8
Mali	ML	9945	5.4	543	583660	46	25.774	43.83	69.604	58	75.004	91	93	206	7542	156	11.5
Malta	MT	379	4.4	11610	37682	5	0.088	0.15	0.239	209	4.639	186	5	34	12239	122	
Marshall Islands	RM	68	0.17	2500	0		0.122	0.208	0.33	200	0.5	225	66	145	7360	159	
Martinique	MB	397	38.11	96000	35289	5	0.1	0.171	0.271	206	38.383	124	1	7	96683	28	
Mauritania	MR	2392	2.8	1171	19828	3	9.598	16.322	25.92	95	28.72	133	90	196	12007	126	4.8
Mauritius	MP	1145	10.9	9520	32503	4	0.26	0.442	0.702	183	11.602	166	6	37	10133	135	6.3
Mayotte	MF	105	0.63	6000	82	0	0.137	0.232	0.369	198	0.999	215	37	106	9513	140	
Mexico	MX	95724	721.4	7536	9349500	433	112.167	190.745	302.912	16	1024.312	14	30	95	10701	131	1.2
Midway Islands	MQ	0	0		0		0.003	0.004	0.007	234	0.007	236	100	236			
Moldova	MD	4312	10.4	2412	119346	13	0.867	1.474	2.341	160	12.741	162	18	68	2955	204	
Monaco	MN	32	0.8	25000	3149	1	0.008	0.013	0.021	231	0.821	218	3	20	25653	66	
Mongolia	MG	2426	4.9	2020	37509	5	54.359	92.439	146.798	28	151.698	59	97	221	62530	36	1.2
Montenegro	MW	620	1.43	2300	31133	4	0.85	1.445	2.294	162	3.72	189	62	136	6001	171	
Montserrat	MH	13	2.03	156000	533	0	0.011	0.018	0.029	229	2.057	200	1	12	158193	12	
Morocco	MO	28217	87.4	3097	507489	41	11.841	20.136	31.976	87	119.376	74	27	89	4231	194	2.9
Mozambique	MZ	18355	12.2	665	52386	7	41.229	70.112	111.341	39	123.541	70	90	195	6731	164	3.3
Myanmar (Burma)	BM	46822	47	1004	978529	70	73.57	125.11	198.68	22	245.68	42	81	172	5247	181	
Namibia	WA	1727	5.8	3358	113049	12	19.504	33.167	52.671	69	58.471	101	90	194	33857	55	
Nauru	NR	11	0.06	5000	296	0	0	0	0	237	0.055	231	1	9	5038	184	
Nepal	NP	22641	25.2	1113	45086	6	4.267	7.257	11.524	119	36.724	128	31	98	1622	226	7.3
Netherlands	NL	15598	301.9	19355	2002522	124	3.296	5.605	8.902	131	310.802	33	3	22	19926	87	3.7
Netherlands Antilles	NT	211	24.27	115000	45948	6	0.178	0.303	0.481	191	24.746	139	2	16	117280	21	
New Caledonia	NC	192	28.8	150000	7578	1	3.317	5.641	8.959	130	37.759	127	24	84	196661	10	
New Zealand	NZ	3628	62.3	17172	400446	34	34.5	58.669	93.169	48	155.469	57	60	132	42853	50	2.8
Nicaragua	NU	4351	7.1	1632	116862	12	26.323	44.763	71.086	57	78.186	89	91	199	17970	99	2.7
Niger	NG	9788	5.5	562	35489	5	12.113	20.599	32.713	86	38.213	126	86	182	3904	195	7.3
Nigeria	NI	107129	135.9	1269	6647396	329	83.879	142.641	226.52	21	362.42	28	63	138	3383	202	2.2
Niue	NE	2	0.01	3000	0		0.014	0.024	0.038	228	0.044	233	86	183	21933	78	
Norfolk Island	NF	3		0	54	0	0.047	0.08	0.127	217	0.127	230	100	227	47173	46	
North Korea	KN	24317	21.5	884	48063	6	7.29	12.397	19.687	103	41.187	122	48	117	1694	224	
Northern Mariana Islan	CQ	53	4.93	93000	8406	1	0.188	0.319	0.507	189	5.436	183	9	47	102565	25	
Norway	NO	4408	106.2	24093	2683676	158	49.15	83.582	132.732	32	238.932	45	56	129	54204	41	4.6
Oman	MU	2265	19.1	8433	918397	66	3.27	5.56	8.83	132	27.93	135	32	100	12331	119	2.4
Pacific Islands (Palau	PS	17	1.5	88000	164	0	0.06	0.102	0.161	214	1.657	204	10	49	97487	27	
Pakistan	PK	137752	274.2	1991	2983446	172	23.698	40.3	63.998	61	338.198	30	19	72	2455	212	1.5
Panama	PM	2698	13.6	5041	117035	12	9.636	16.386	26.022	94	39.622	123	66	143	14686	108	3.9
Papua New Guinea	PP	4405	10.2	2316	155818	16	88.788	150.988	239.776	20	249.976	41	96	219	56748	40	4.8
Paraguay	PA	5093	17	3338	377703	32	24.327	41.369	65.696	60	82.696	84	79	168	16237	103	3.5
Peru	PE	24362	87	3571	1038568	73	169.918	288.953	458.871	9	545.871	20	84	179	22407	73	2.7
Philippines	RP	73419	179.7	2448	586314	46	28.21	47.972	76.182	54	255.882	39	30	96	3485	201	1.9
Pitcairn Islands	PC	0		0	0		0.003	0.004	0.007	233	0.007	235	100	228	137695	15	
Poland	PL	38648	226.7	5866	3088214	177	10.258	17.444	27.702	93	254.402	40	11	54	6583	166	0.7
Portugal	PO	9934	116.2	11697	1271063	86	4.565	7.762	12.327	116	128.527	64	10	48	12938	116	2.8
Puerto Rico	RQ	3916	36.9	9423	729006	55	3.564	6.061	9.625	127	46.525	112	21	77	11881	128	
Qatar	QA	560	10.7	19107	472783	39	0.703	1.195	1.898	167	12.598	163	15	63	22496	72	
Reunion	RE	692	29.76	43000	32771	4	0.091	0.154	0.244	207	30	132	1	10	43353	49	
Romania	RO	22535	105.7	4690	798291	59	8.343	14.188	22.531	100	128.231	65	18	67	5690	175	0.7
Russia	RS	147264	796	5405	23889006	926	3609.45	6138.03	9747.48	1	10543.48	1	92	204	71596	32	
Rwanda	RW	7738	3.8	491	7063	1	3.335	5.671	9.006	129	12.806	161	70	156	1655	225	4.9

Table 2 (*Continued*)

Country	Fips Code	Population (1000's) (1995)	PPP of GDP (1995) (Billions)	PPP per Capita	Total Light Energy from DMSP OLS	PPP ($Billions) by DMSP Proxy	ESP ($Billions) Land	ESP ($Billions) Marine	ESP ($Billions) Total(Land + Marine)	Rank ESP	SEP ($Billions) Sum of PPP and ESP	Rank SEP	%ESP	Rank %ESP	SEP/Capita	Rank SEP/Capita	GDP per Energy Use
San Marino	SM	25	0.5	20000	4688	1	0.001	0.001	0.002	236	0.502	224	0	3	20092	86	
Sao Tome and Principe	TP	148	0.52	3500	106	0	0.854	1.452	2.306	161	2.824	193	82	173	19080	95	2.6
Saudi Arabia	SA	19494	189.3	9711	6595797	327	19.576	33.289	52.865	68	242.165	44	22	81	12423	118	1.1
Senegal	SG	8762	14.5	1655	328459	29	19.907	33.852	53.759	66	68.259	94	79	166	7790	153	6.3
Serbia	SR		20.6		471503	39	2.422	4.119	6.541	143	27.141	136	24	87			
Seychelles	SE	78	0.4	5128	2097	0	0.231	0.392	0.623	185	1.023	213	61	134	13116	115	2.9
Sierra Leone	SL	4428	4.4	994	184923	18	14.856	14.105	28.962	92	33.362	130	87	184	7534	157	2.4
Singapore	SN	3462	66.1	19093	265139	24	0.145	0.246	0.391	196	66.491	98	1	6	19206	93	1.6
Slovakia	LO	5384	39	7244	849123	62	1.317	2.24	3.557	152	42.557	120	8	46	7904	151	
Slovenia	SI	1984	22.6	11391	212318	20	0.486	0.827	1.314	172	23.914	143	5	36	12053	124	
Solomon Islands	BP	396	1	2525	364	0	6.58	11.189	17.768	106	18.768	150	95	213	47395	45	3.9
Somalia	SO	10217	3.6	352	8918	2	16.067	27.322	43.389	73	46.989	111	92	202	4599	190	
South Africa	SF	42465	215	5063	2761139	161	39.698	67.507	107.205	41	322.205	32	33	101	7588	155	1
South Georgia	SX	0	0		0		0.395	0.672	1.067	177	1.067	212	100	231			
South Korea	KS	45850	590.7	12883	4205051	227	7.749	13.178	20.928	102	611.628	18	3	24	13340	114	
Spain	SP	39330	565	14366	6888845	338	18.423	31.328	49.751	70	614.751	17	8	45	15631	105	3.6
Sri Lanka	CE	18665	65.6	3515	153350	16	5.127	8.718	13.845	113	79.445	86	17	66	4256	192	5.1
St. Helena	SH	7	0.14	20600	0		0.112	0.191	0.303	204	0.447	227	68	147	63876	35	
St. Kitts and Nevis	SC	42	2.17	51700	4604	1	0.114	0.193	0.307	202	2.478	196	12	58	59010	38	7.3
St. Lucia	ST	146	0.6	4110	4533	1	0.07	0.119	0.188	212	0.788	219	24	85	5400	178	7.9
St. Pierre and Miquelon	SB	7	0.77	110000	1572	0	0.09	0.153	0.243	208	1.013	214	24	86	144653	14	
St. Vincent and the Grenadines	VC	119	2.71	22800	1925	0	0.135	0.23	0.365	199	3.078	191	12	56	25865	64	
Sudan	SU	27899	244.12	8750	2669412	157	107.103	182.133	289.236	17	533.353	21	54	126	19117	94	12.1
Suriname	NS	437	3.85	8800	16357	3	32.95	56.033	88.983	49	92.829	80	96	218	212423	7	1.1
Svalbard	SV	2		0	0		6.561	11.158	17.72	107	17.72	153	100	229	7383137	1	
Swaziland	WZ	1032	12.07	11700	14485	2	0.833	1.417	2.25	163	14.325	158	16	64	13881	112	3
Sweden	SW	8854	177.3	20025	5486855	281	69.954	118.959	188.913	23	366.213	27	52	124	41361	52	3.3
Switzerland	SZ	7122	158.5	22255	772920	58	4.013	6.824	10.836	122	169.336	52	6	40	23777	68	7.4
Syria	SY	14951	91.2	6100	1257501	85	4.41	7.499	11.909	118	103.109	79	12	55	6896	162	
Taiwan	TW	21535	290.5	13490	1243245	85	2.066	3.513	5.579	145	296.079	35	2	15	13749	113	
Tajikistan	TI	5988	6.4	1069	118721	13	5.439	9.248	14.687	112	21.087	146	70	154	3522	200	0.5
Tanzania	TZ	29461	23.1	784	260950	24	100.225	170.437	270.661	19	293.761	36	92	200	9971	136	4.5
Thailand	TH	60088	416.7	6935	5645754	288	35.632	60.593	96.225	46	512.925	23	19	70	8536	145	2.2
the Isle of Man	IM	76	8.21	108000	7502	1	0.156	0.265	0.421	195	8.629	177	5	33	113542	22	
Togo	TO	4736	4.1	866	137322	14	2.55	4.336	6.886	142	10.986	167	63	139	2320	216	6.9
Tonga	TN	99	1.61	16300	1160	0	0.112	0.191	0.303	203	1.917	201	16	65	19360	91	4.8
Trinidad and Tobago	TD	1276	16.2	12696	90304	10	0.82	1.395	2.215	164	18.415	151	12	57	14432	110	0.7
Tunisia	TS	9326	37.1	3978	435165	36	3.239	5.508	8.747	133	45.847	113	19	73	4916	186	2.4
Turkey	TU	63674	345.7	5429	2027962	126	48.163	81.904	130.067	34	475.767	24	27	90	7472	158	1.8
Turkmenistan	TX	4572	11.5	2515	444221	37	12.594	21.417	34.011	85	45.511	114	75	161	9954	137	
Turks and Caicos Islands	TK	2	0.15	77000	1801	0	0.735	1.25	1.985	165	2.139	199	93	205	1069427	4	
Uganda	UG	20605	16.8	815	1433650	95	57.621	97.988	155.609	25	172.409	51	90	197	8367	146	22.6
Ukraine	UP	50719	174.6	3443	3055707	175	25.762	43.81	69.572	59	244.172	43	28	91	4814	187	0.4
United Arab Emirates	TC	2308	70.1	30373	1451971	96	1.103	1.876	2.979	155	73.079	92	4	30	31663	57	
United Kingdom	UK	58800	1138.4	19361	5974370	301	48.693	82.805	131.499	33	1269.899	10	10	51	21597	79	3.5
United States	US	267661	7247.7	27078	123789427	3511	771.784	1312.45	2084.24	4	9331.936	2	22	82	34865	53	2.6
Uruguay	UY	3223	24.4	7571	398193	34	9.348	15.897	25.245	98	49.645	109	51	123	15403	106	4.6
Uzbekistan	UZ	23672	54.7	2311	1235096	84	43.667	74.258	117.925	35	172.625	50	68	150	7292	160	0.3
Vanuatu	NH	176	2.11	12000	22681	3	3.593	6.111	9.704	126	11.816	164	82	175	67136	33	2.9
Venezuela	VE	22576	195.5	8660	3368548	189	124.026	210.912	334.939	12	530.439	22	63	140	23496	71	1.2
Vietnam	VM	75123	97	1291	1442889	95	22.869	38.889	61.758	63	158.758	56	39	109	2113	220	7.5
Virgin Islands	VQ	13	1.63	125000	30685	4	0.278	0.473	0.751	182	2.376	197	32	99	182733	11	
Wake Island	WQ	0	0		0		0.015	0.026	0.041	227	0.041	234	100	235			
Wallis and Futuna	WF	14	0.28	20000	0		0.076	0.13	0.207	210	0.487	226	42	113	34753	54	
West Bank	WE	1664	208	125000	197323	19	0.384	0.654	1.038	178	209.038	47	0	4	125624	17	
Western Sahara	WI	228	2.51	11000	15648	2	2.774	4.718	7.492	138	10	169	75	163	43859	48	
Western Samoa	WS	183	0.4	2186	863	0	0.286	0.486	0.771	181	1.171	209	66	144	6399	167	
Yemen	YM	15214	37.1	2439	251622	23	7.027	11.95	18.978	105	56.078	105	34	102	3686	197	
Zaire	CG	47440	16.5	348	1981834	123	365.28	621.174	986.454	5	1002.954	15	98	223	21142	82	
Zambia	ZA	9350	8.9	952	114927	12	38.867	66.094	104.961	42	113.861	76	92	201	12178	123	1.8
Zimbabwe	ZI	11423	18.1	1585	122711	13	14.435	24.548	38.984	78	57.084	102	68	149	4997	185	1.4

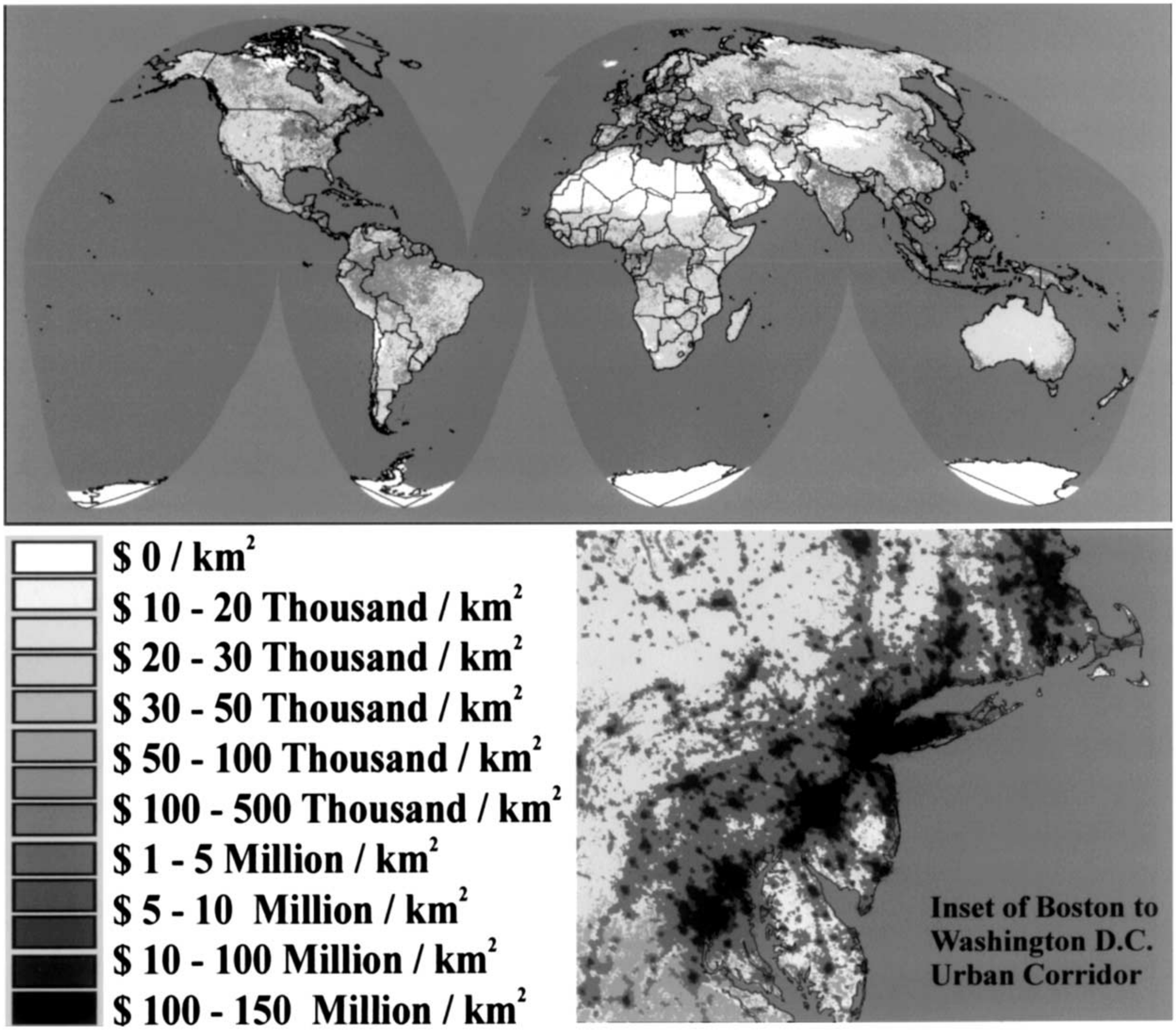


Fig. 4. Subtotal Ecological–Economic Product (SEP = GDP + ESP) at 1 km^2 resolution (w/ inset Boston, DC).

source cited for these 'Eco-Deficit' calculations was the *Living Planet Report* of the World Wide Fund for Nature (WWF), Gland, Switzerland. The 'Eco-Deficit' reported in the 2001 ESI report only correlated with the '97 Eco-Deficit of Wackernagel with an R^2 of 0.13. This may be due to differences in number of nations for which it was measured; nonetheless, it raises questions regarding which numbers to use. In general, the numbers used in this analysis were: (1) Empirically derived %ESP Index ($N = 210$); (2) Eco-Deficit numbers from Wackernagel et al. (1997) ($N = 52$), and ESI numbers from World Economic Forum ($N = 122$).

Using the absolute scores for these various indices is problematic for statistical reasons. All correlations reported are based on the *ranks* of the figures reported. This means that the regressions are non-parametric in nature. This is appropriate in the sense that we are more likely to be successful at measuring *relative* rather than *absolute* quantities. Also, The ESI figures were converted to a standard normal distribution or 'normalized' after the final means of the five 'core' sub-indices were calculated. Assumption of a normal distribution of ESIs for the nations of the world is probably not warranted. The non-parametric methods used here lack the potential statistical power of using the absolute numbers reported; however, the results are more robust and less influenced by outliers in the data.

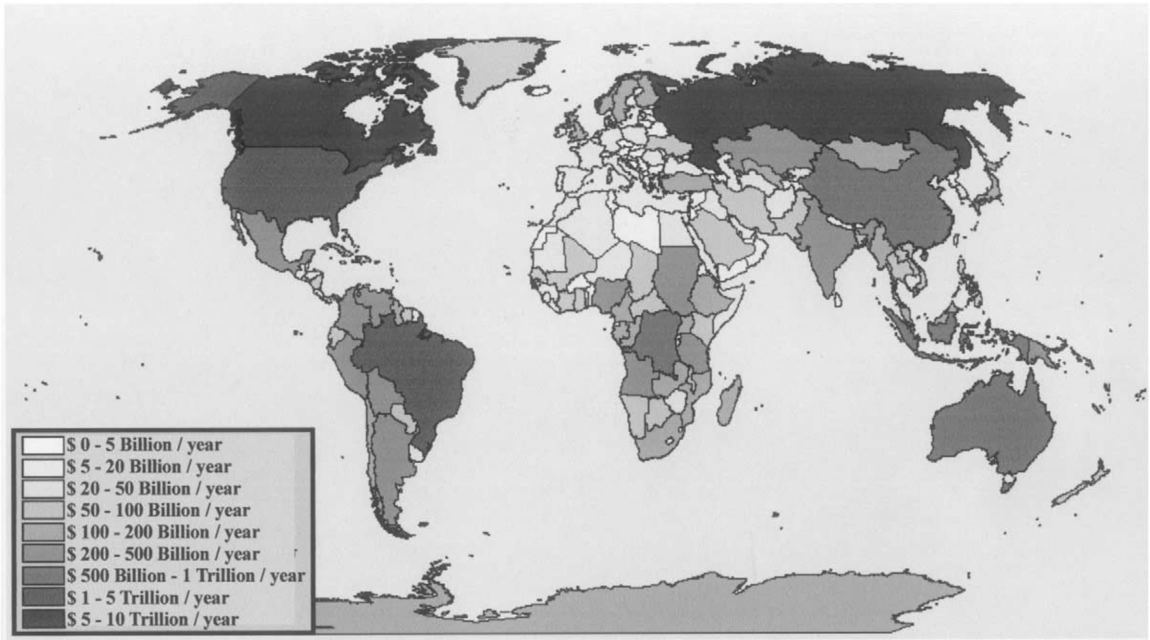


Fig. 5. Aggregated National Map (choropleth) of Ecosystem Service Product (ESP).

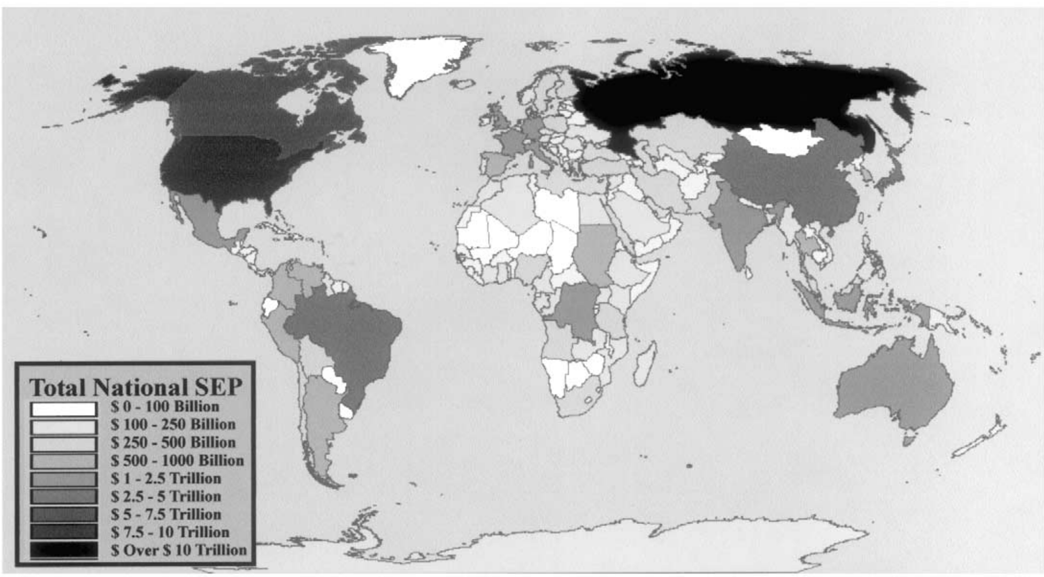


Fig. 6. Aggregated National Map (choropleth) of Subtotal Ecological–Economic Product (SEP).

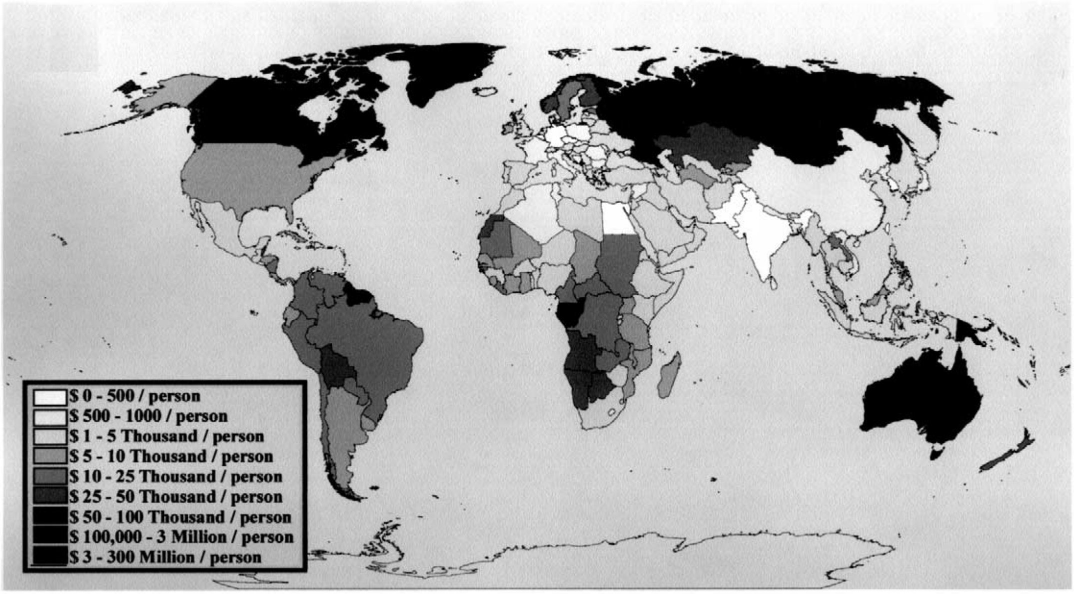


Fig. 7. Aggregated National Map (choropleth) of SEP/Capita.

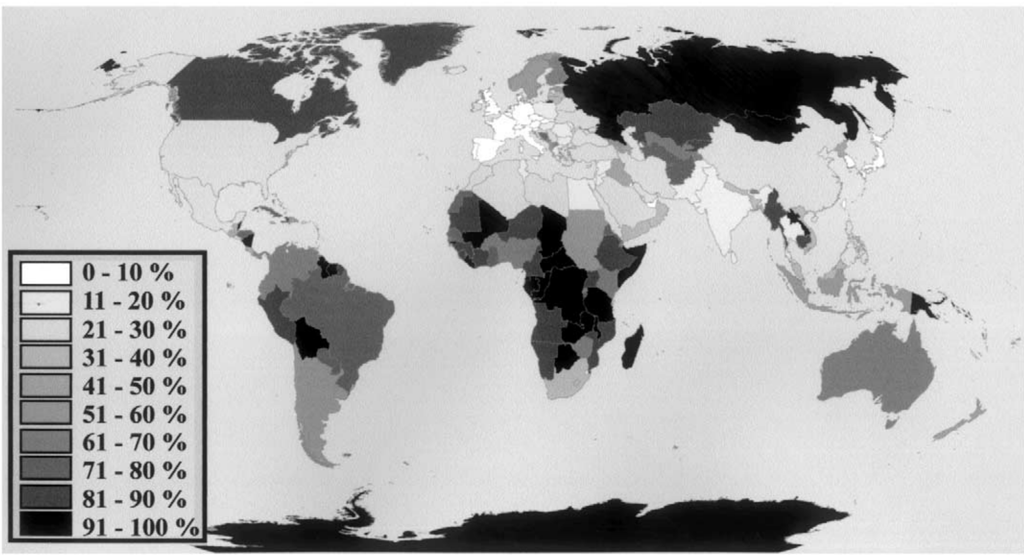


Fig. 8. Aggregated National Map (choropleth) of %ESP (= 100 × (ESP/SEP)).

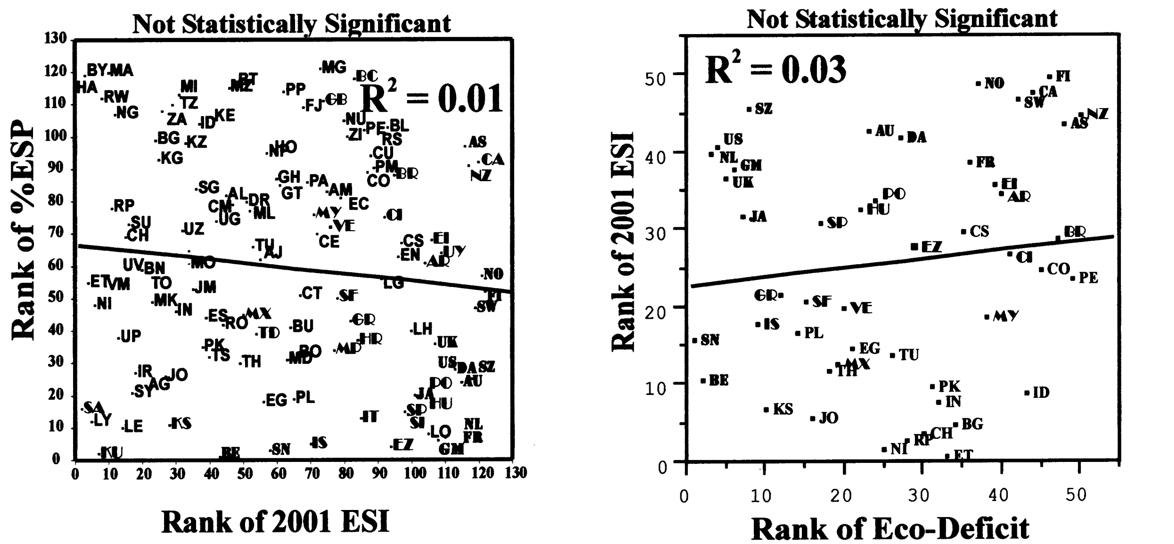
Table 3 is a correlation matrix of the three variables and their ranks in addition to several other relevant variables. The ranks were ordered so that higher ranks indicated 'better' numbers for all indices. These correlations will not agree exactly with all previously published correlations (particularly those in the ESI report) because they have a different sample size. Some interesting things to note in this table are that population density correlates negatively with all the indices. GDP per capita on the other hand correlates positively with only the ESI but negatively with all other indices.

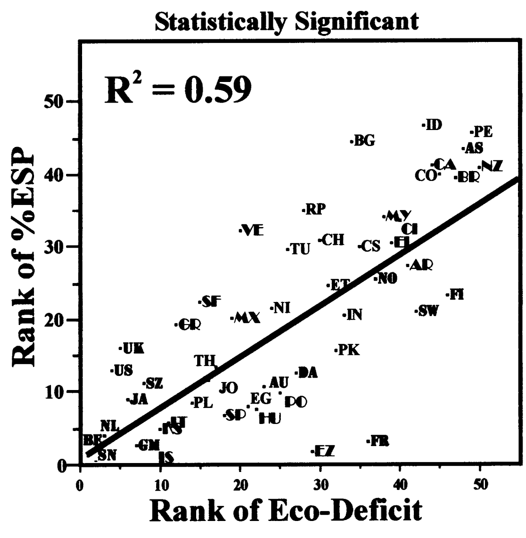
Table 3
Correlation matrix of variables discussed in paper

	PPP of GDP (1995)	PPP per Capita	ESP	ESP/Capita	PPP by Night Light Proxy	SEP	%ESP	Rank %ESP	SEP/Capita	Rank SEP/Capita	Rank eco-deficit (1997)	Rank eco-deficit (1997)	2001 ESI	Rank of 2001 ESI
PPP of GDP (1995)	1.00	0.27	0.21	−0.02	0.90	0.69	−0.15	−0.11	0.50	−0.42	−0.20	−0.25	0.05	0.06
PPP per Capita	0.27	1.00	0.01	0.19	0.30	0.15	−0.26	−0.33	−0.29	0.39	−0.12	−0.23	0.77	0.72
ESP	0.21	0.01	1.00	0.03	0.42	0.85	0.50	0.51	0.11	−0.26	0.05	0.05	0.14	0.14
ESP/Capita	−0.02	0.19	0.03	1.00	−0.04	0.01	0.18	0.16	−0.05	0.01	0.27	0.22	0.17	0.15
PPP by Night Light Proxy	0.90	0.30	0.42	−0.04	1.00	0.79	0.06	0.09	0.25	−0.36	−0.16	−0.21	0.15	0.15
SEP	0.69	0.15	0.85	0.01	0.79	1.00	0.29	0.32	0.35	−0.42	−0.07	−0.10	0.13	0.13
%ESP	−0.15	−0.26	0.50	0.18	0.06	0.29	1.00	0.98	−0.05	−0.08	0.62	0.67	0.10	0.05
Rank %ESP	−0.11	−0.33	0.51	0.16	0.09	0.32	0.98	1.00	−0.01	−0.13	0.61	0.68	0.07	0.01
SEP/Capita	0.50	−0.29	0.11	−0.05	0.25	0.35	−0.05	−0.01	1.00	−0.41	−0.02	0.05	−0.32	−0.38
Rank SEP/Capita	−0.42	0.39	−0.26	0.01	−0.36	−0.42	−0.08	−0.13	−0.41	1.00	0.12	0.07	0.44	0.41
Eco-deficit (1997)	−0.20	−0.12	0.05	0.27	−0.16	−0.07	0.62	0.61	−0.02	0.12	1.00	0.85	0.26	0.21
Rank eco-deficit (1997)	−0.25	−0.23	0.05	0.22	−0.21	−0.10	0.67	0.68	0.05	0.07	0.85	1.00	0.21	0.13
2001 ESI	0.05	0.77	0.14	0.17	0.15	0.13	0.10	0.07	−0.32	0.44	0.26	0.21	1.00	0.96
Rank of 2001 ESI	0.06	0.72	0.14	0.15	0.15	0.13	0.05	0.01	−0.38	0.41	0.21	0.13	0.96	1.00

Note: $N = 50$ for all correlations. Other relationships reported in paper may be based on higher N when available.

Fig. 9 summarizes the three critical comparisons buried in Table 3 as scatterplots in which the points represent all the nations for which numbers were available for pair-wise comparisons. The essence of this figure demonstrates that there is no statistically significant relationship between the %ESP and ESI, nor is there any significant relationship between ED and ESI. However, the correlation between the %ESP Index and ED is both positive and statistically significant. Higher GDP per capita countries tended to dominate the lower levels of both the ED and the %ESP Index. Aggregate national population density seems to be a significant contributor to this effect in that





Key for labeling of Major Nations in Scatterplots

High GDP/Capita Countries	Fips Code	Medium GDP/Capita Countries	Fips Code	Low GDP/Capita Countries	Fips Code
GDP/Cap >$20,000		$20K>GDP/Cap >$3K		GDP/Cap<$3,000	
Australia	AS	Argentina	AR	Bangladesh	BG
Austria	AU	Brazil	BR	China	CH
Belgium	BE	Chile	CI	Colombia	CO
Canada	CA	Czech Republic	EZ	Costa Rica	CS
Denmark	DA	Greece	GR	Egypt	EG
Finland	FI	Hungary	HU	Ethiopia	ET
France	FR	Ireland	EI	India	IN
Germany	GM	Israel	IS	Indonesia	ID
Japan	JA	Malaysia	MY	Jordan	JO
Netherlands	NL	Mexico	MX	Nigeria	NI
Norway	NO	New Zealand	NZ	Pakistan	PK
Singapore	SN	Portugal	PO	Peru	PE
Sweden	SW	South Africa	SF	Phillipines	RP
Switzerland	SZ	Spain	SP	Poland	PL
United Kingdom	UK	Venezuela	VE	South Korea	KS
United States	US			Thailand	TH
				Turkey	TU

Note #1: R^2 reported are derived from ranked or non-parametric regression

Note #2: Higher ranks in all cases suggest higher sustainability

Fig. 9. Scatterplots of %ESP (Percent Ecosystem Services Product), ESI (2001 Environmental Sustainability Index), and Eco-Deficit (ED).

the only high GDP per capita nations with higher ranks according to the both the ED and the %ESP were Canada and Australia.

4. Discussion

The data and maps we have assembled allow for some interesting new pictures of the world to be constructed and for some interesting new questions to be posed. One can ask, for example, which countries have the highest percentage of support of human welfare arising from ecosystem services relative to marketed goods and services? Fig. 8 (%ESP) shows an interesting pattern as an answer to that question, with countries as disparate as Canada, Russia, Nicaragua, and Botswana ranking high, and most of Europe and Japan ranking low. Northern industrial countries (with the exception of Canada) have focused on built capital and have depleted their internal natural capital. Another question relates to the total 'wealth' of individuals, when wealth is considered as the sum of marketed (GDP/capita) and non-marketed (ESP/capita) contributions. Fig. 7 (and Table 2) shows that Canada, Greenland, Surinam, Gabon, and several small island countries like the Bahamas and the Netherlands Antilles rank highest. A second tier includes Scandinavia, Russia, Australia, New Zealand, Bolivia, and Botswana. A third tier includes The US (ranked 53rd out of 227), most of Europe and parts of Africa and South America, while China, India and parts of Africa are ranked lowest. While this measure certainly leaves out many factors which contribute to real welfare (including distribution of wealth, political freedom, etc.), it does present a very different picture of wealth (and poverty) than the conventional GDP statistics.

The %ESP indicator presented in this paper is proposed in the spirit expressed by the developers of the Environmental Sustainability Index (i.e. *to be part of a transparent*, *interactive process that draws on rigorous statistical*, *environmental*, *and analytic expertise to quantify environmental sustainability*). This indicator is significantly distinct from other related measures primarily because of the high spatial resolution of the data from which it was derived. Nonetheless, it remains a static measure of both marketed and non-marketed value. However, the high spatial resolution of this data does enable future research in both the spatial and temporal attributes of ecosystem service valuation. For example, many ecosystem services provide benefits at spatial scales ranging from the local to the global (e.g. carbon sequestration may be considered a global service whereas water purification may be considered a local service). The spatially explicit nature of this data allows for the use of spatial context in the valuation of ecosystem services (e.g. a wetland purifying the water for the citizens of a nearby urban area in a developed country may be valued much more than a wetland in Siberia). The nature of this data also allows for spatially explicit results in a dynamic modeling environment; for example, one could envision the rural population of a certain region being adversely affected by some economic force that changes their propensity to harvest a nearby forest for timber. The development of the spatially explicit economic and ecological data described here is an important step on the way to building dynamic models that can capture the behaviors of complex adaptive systems.

5. Conclusion

This paper presents a spatially explicit map (1 km^2 resolution) of marketed economic activity derived from nighttime satellite imagery and nationally aggregate measures of GDP (Fig. 2), non-marketed economic activity derived from ecosystem service valuation and a global land-cover dataset (ESP, Fig. 2), in addition to several nationally aggregated measures and other manipulations of these maps (Figs. 5–7). One particular measure derived from these datasets was percent of economy derived from ecosystem services (%ESP, Fig. 8). %ESP correlated significantly with the Eco-Deficit indicator of Wackernagel, and did not correlate at all with the 2001 Environmental Sustainability Index (Fig. 9). The spatially explicit measures of market and non-market activity provide a mechanism for incorporating spatial context into ecosystem service valuation and enhancing the nature of dynamic models that attempt to characterize changes over time to the value of ecosystem services. Certainly, much remains to be done in assessing the 'real' wealth of nations and the relative contribution of ecosystem services to that wealth. We have provided only a first step in the direction of making that picture more spatially explicit and more comprehensive. But that step has shown that the path is likely to be a fruitful one.

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