Technical Description of the new Measures for Ecosystem Services and Urban Infrastructure

DRAFT TEXT – Subject to Revision

As described below, one measure still to be selected for the Ecosystem Services component so the detailed summary results are preliminary

Ian Noble - 29 July 2012

Adding Ecosystem Services to the Core Life Support Sectors

The GAIN Index was initially launched in 2011 with a strong structure to help guide the selection of measures (i.e. the variables that make up the Index). For the vulnerability component of the Index the structure was in the form of a matrix with one axis a set of core life support "sectors" covering Food, Water, Health and an Infrastructure sector (made up of Coastal, Transport and Energy) and the other axis a set of components of vulnerability; Exposure, Sensitivity and Capacity (Fig. 1). In releasing the 2011 version we recognized that many would argue for the inclusion of a sector representing Ecosystem Services among the core life support sectors and the need to include additional urban oriented sectors in the Infrastructure section. This document describes the measures to complete the plan for the vulnerability component of the original GAIN Index.

Rationale for the Ecosystem Services sector

Ecosystem services are the multitude of processes that humans rely upon to support their lives and livelihoods. These processes provide food and clean water, regulate the climate, support nutrient cycling and provide cultural experiences. In developing the GAIN vulnerability measures we have sought to choose sets of measures that are tangible, simple but directly relevant to the concept to be captured. It is obviously difficult to capture ecosystem services in six simple measures so the use of integrative, synthetic measures was also considered.

The Measures

Exposure

To be consistent with the other core sectors, we sought a measure of exposure that reflects the size of the likely impacts of climate change over the next few decades. This has proved difficult. An obvious measure is the effect of climate change on the distribution of the ecosystems and biomes[1] that provide the services on which we depend. There are

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[1] Biomes are a higher order structure than ecosystems. They are made up of a collection of ecosystems and "ecoregions" representative of a particular broad climate and soil type. There are several schemes describing the Earth's biomes, but most recognize 10 to 20 biomes for terrestrial ecosystems.

estimates of the proportion of the land surface on which the type of biome might be expected to change under projected climate change. However, most of these estimates are based on what is now old projections and models and most do not account for these changes on a country by country scale as this is rarely relevant to the question at hand. We are still seeking a measure that appropriately captures this element. ***Advice on this will be most welcome.***

Another measure of exposure is how much we depend upon ecosystem services to provide the basis of our economies. Here we have used the work on natural capital, derived largely from the World Bank, that seeks to estimate human dependency on "natural capital", which is the stock ecosystem goods that can deliver ecosystem services in the future. This work seeks to capture and value the full range of natural capital including both ecosystem services and natural resources such as minerals and fossil fuels. In our measure we choose to focus only on the value of those services derived from ecosystems and expressed as a proportion of the GDP (see ENC – Dependency on Natural Capital below for a complete description).

Sensitivity

To capture the component of sensitivity we again use a synthetic measure. In this case we use the "Ecological Footprint", which has been gaining increasing acceptance as a proxy for the total impact of human livelihoods on the Earth and its sustaining systems. The ecological footprint seeks to measure the number of hectares of land and ocean needed to support the livelihood of each individual within a city, country or region. It also compares this with the support that the territory of each country can provide per hectare. Some countries have a net deficit; i.e. the population needs more hectares than can be provided locally and thus draw upon resources in other countries and/or deplete resources at greater than a sustainable rate. Some have a net surplus. We use this measure of deficit or surplus as an indicator of how sensitive a country might be to climate change. Countries with a surplus are either able to manage their demand to match their supply or have sufficient land area and associated resources to meet their demand. In either case they are in a better position to meet the challenges of adapting to climate change than a country that is in deficit. Note that this measure is simply seeking to capture the sensitivity of a country and not the ethical situation. The Netherlands, despite high standards of sustainability etc is in net deficit and makes a net drawdown upon resources from elsewhere, whereas Australia because of its low population, large area and abundant resources is in surplus. [See ENC – EEF – Ecological Footprint Surplus/Deficit]

As a second and more qualitative measure of sensitivity we have used an estimate of the health of the country's ecosystems via the proxy of the proportion or number of threatened species within that country. Threatened species indicate either severe pressure on those ecosystems or the inability to manage those ecosystems effectively, or a combination of both. In either case, the ecosystems are likely to be more sensitive to additional threats associated with climate change. [See ETS – Threatened Species]

Capacity

As a measure of capacity to adapt we have chosen the ability of a country to provide conservation protection to its biomes and its ability and its willingness to engage in international cooperative efforts using multilateral environmental agreements as the proxy.

Protection of biomes (and their component ecosystems) is an indication of a capacity of the national institutions to make decisions to undertake conservative management of significant components of the landscape to provide resources and buffers for the future. This is a capacity that is likely to translate into effective reactions to the challenges of climate change. [See EPB Protected Biomes]

Similarly the capacity to work effectively in multilateral efforts to protect the environment is an indicator of a capacity to plan and cooperate in adapting to the effects of climate change. Our proxy does not capture the effectiveness of such engagement in multilateral processes, but work is underway to improve on this. [See EIC – Engagement in Multilateral Environmental Agreements].

Rationale for the Urban Sector

The urban sector is of particular importance in effective adaptation to a changing climate as it is also the focus of many other social and economic changes. Internally generated rapid economic and population growth in cities is a challenge in its own right, but it is often exacerbated by substantial migration from rural areas driven as much by the poverty of rural regions as by the attractiveness and opportunities of the cities. In selecting the measures we have tried to capture both these elements; one sector representing the threat to cities and the other the process of rapid urbanization.

Cities present their own particular physical challenges in adaptation. Many are either coastal or riverine and often in location particularly prone to flooding. Dense populations can lead to impacts being magnified with huge numbers of people being affected by events that are small in area. On top of this, cities are usually the financial, administrative and intellectual hub of society so disruption to their smooth running has significant flow on effects to the rest of the country.

The Measures

Exposure

There are many measures of the exposure of urban regions to climate and related hazards. Some are already included indirectly in other components of the GAIN Index; e.g. the proportion of the population exposed to seal level threats in the coastal sector. Here we have chosen two measures of exposure. The first seeks to capture the concentration of the population and the associated finance, skills etc in the largest city of the country [See UUC – Urban Concentration]. As a measure of exposure to the challenges associated with rapid urbanization we have chosen a direct measure in the excess in growth rate of urban areas compared with rural areas in a country. [See UEX - Excess Urban Population Growth]

Sensitivity

Again there are many measures of the quality of urban life, which in turn might indicate the sensitivity of urban areas to the additional impacts of a changing climate. Some, such as comparative levels of poverty in urban versus rural areas would be suitable but are inconsistently recorded with many countries missing data. We have used the UN Millennium Development Goal indicator of the percentage of the urban population living in slums which is available for most developing countries and can be set to a default value for

developed countries. To assess the sensitivity of urban areas to pressures for more rapid urbanization we have used a measure of the desirability of urban life versus rural life. We have used the difference in access to improved sanitation as it is well reported.

Scoring

Each of the measures described above has been obtained from appropriate reliable sources for as many countries as possible (always >75% of the target of all UN members[2]). The distribution of values of the measure was examined including the mean, median and 5%, 10%, 90% and 95% percentiles and upper and lower bounds selected. These bounds are at "natural" values (such as 0 or 100%) or within the range of the 5% and 10% or 90% and 95% percentiles. The countries scores were then normalized to a range of 0 to 1 between the bounds selected. Occasionally the bounds were varied to provide an average score across all countries within the range of about 0.3 to 0.5 and a standard deviation of about 0.2.

The original values, bounds and scores derived for each measure are shown in the attached spreadsheet.

Each measure was assessed for how independent its score was from the other measures as we sought to select measures that were as independent of each other as possible – i.e they provided different insights into the overall assessment of vulnerability. They were also assessed against existing measures contributing to the Vulnerability Score and against common metrics such as GDP per capita and the Human Dimension Index.

Overall, poor countries are more vulnerable in relation to their Ecosystem Services than wealthy but as Fig 2 shows there is a wide dispersal of scores across all incomes. The separate measures for the Ecosystem Services component are relatively independent with the highest correlation being between the Engagement in Multilateral Environmental Conventions and the (Ecosystem) Natural Capital Dependency scores (R^2=0.21). Thus each measure appears to be contributing different information to the overall Ecosystem Services score.

The measures contributing to the Ecosystem Services and Urban Sectors show low correlations with the measures already included in the 2011 Vulnerability Score (most R^2<0.1). They are often slightly more correlated with the 2011 Readiness measures. The Dependency on Natural Capital and Urban Slums measures show the highest correlations (average about R^2 of 0.2 and 0.3 respectively). The highest correlations are logical – e.g. Urban Slums with Energy Access and Health Diseases (R2 about 0.7). This indicated that overall the new measures are introducing new information into the GAIN Vulnerability Score.

Effect of the New Measures on Vulnerability Scores and Rankings

The net effect of the new measures on average vulnerability is small (Fig. 3) with the average vulnerability score rising from 0.330 to 0.349, and an average absolute change of 0.027. The largest changes are increases of 0.05 or more among middle vulnerability countries such as Barbados, Vietnam and Moldova, and among small island states with Palau showing the greatest with an increase of 0.134. The largest falls occur amongst some

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[2] List of 192 countries; South Sudan cannot be included

of the most vulnerable countries (Central African Republic, Dominica, Senegal) and among wealthy countries (Luxemburg, Belgium, Canada) with falls of 0.03 to 0.05.

These changes have an effect on the rankings with some countries becoming more vulnerable by 30 or more positions (e.g. Moldova, Palau, Barbados and Vietnam) and others reducing their vulnerability ranks by more than 25 positions with Russia showing the greatest improvement in vulnerability rank (31 positions). But the overall absolute change in rank is 10 positions with a third changing by 5 positions or fewer. Only 3 of the original 20 least vulnerable countries fell out of that list (Fig 4) while in the 20 most vulnerable countries 6 countries – all African - rise out of that zone.

Summary
The value of adding the new measures is that they add a much richer set of information underlying the iconic GAIN and Vulnerability scores. The Ecosystem Services measures complete the commonly recognized of human life support 'sectors' - food, water, health and now ecosystem services – while the urban measures add an essential component of infrastructure. That these measures did not hugely affect the overall vulnerability scores and rankings demonstrates the inherent robustness of the GAIN index and its value as an icon in attracting attention and raising awareness about the importance of vulnerability to climate events and readiness to adapt to changing climatic circumstances.

Summary of the New Measures

		Exposure	Sensitivity	Capacity
Ecosystem services	Quantity	Exx tbd	EEF - Ecological Footprint Surplus/Deficit	EPB - Protected Biomes
	Quality	ENC - Dependency on Natural Capital	ETS - Threatened Species	EIC - Engagement in International Environmental Conventions
Urban		UUC - Urban Concentration (% urban population in largest city)	UUS - % Urban Population Living in Slums	--
Urbanisation (Rural to urban migration)		UEX - Excess Urban Population Growth (compared to rural)	UAS - Urban Access to Sanitation (compared to rural)	--

Ecosystem Services

Measure: tbd
Description: Seeking a measure of the threat from climate change to ecosystems/biomes.
Rationale: This will match the other core sectors (Food, Water, Health) each of which has a measure that deals with the exposure to future climates (e.g. Projected temperature increase, projected agricultural yields).
Source:
Coverage:
Time Series:
Issues: Many projections of biome shifts are quite dated (i.e. old GCM modeling, limited selection of GCMs and most based on a single ecological model). There are several more up-to-date projections, but none express results on a per country basis as it is not a mainstream variable likely to be used in analyses.

Measure: *EEF - Ecological Footprint Surplus/Deficit*
Description: The ecological footprint measures the number of hectares of land and water, both within and outside the country, to supply the average demand on the ecosystems services by the lifestyles of the population of each country. This is compared with the estimated capacity of a country's ecosystems to regenerate and maintain ecosystem services for either internal use or export. This measure uses the surplus or deficit of capacity to supply over the demand within each country.
Rationale: A country with a surplus has the capacity to produce more from within its boundaries and thus is likely to have more options to adapt to a changing climate.

Source: Results from National Footprint Accounts 2011 edition, www.footprintnetwork.org extracted on 12 July 2012.
Coverage: 151 countries
Time Series: Technically available since 1961, but will require some effort to extract them.
Issues: (i) The ecological footprint has been in use since 1992 and the subject of considerable scientific testing and debate. The methods of calculation are becoming more standardized and it is gradually being taken into account in policy making and national reporting. Here we use the data provided by the Global Footprint Network led by one of the originators of the idea, Mark Wakernagel.
(ii) We also exclude the carbon footprint component of the Ecological Footprint since this does not directly affect sensitivity relating to adaptation. The urban component is also effectively excluded as it appears in both the demand and supply side of the equation.
(ii) There is a similarity in concepts between the Ecological Footprint and the Natural Accounting approach used in ENC. We have checked the correlations between the two measures and the data that goes into constructing them. While there is a strong correlation between some of the components (e.g. Grazing land capital and footprint) as they are based on the same or similar data (Ha of grassland per capita), there is little correlation between the two measures used (r^2 is -0.024 and Fig 5) as ultimately the data are used to calculate quite different measures – a measure of capital in one case and a measure of supply in the other.

Measure: *EPB – Protected Biomes*
Description: Taken directly from the Yale Environmental Performance Index (EPI) which defines it as follows ... "The weighted percentage of biomes under protected status, where the weight is determined by the size of biomes within a country. Countries are not rewarded for protecting beyond 17% of any given biome (i.e., scores are capped at 17% per biome) so that higher levels of protection of some biomes cannot be used to offset lower levels of protection of other biomes."
Rationale:. Countries with good protection of their core ecosystem types are likely to have the capacity to implement a wider range of actions to continue to protect and manage ecosystem services under a changing climate.
Source: Emerson, J.W., A. Hsu, M.A. Levy, A. de Sherbinin, V. Mara, D.C. Esty, and M. Jaiteh. 2012. 2012 Environmental Performance Index and Pilot Trend Environmental Performance Index. New Haven: Yale Center for Environmental Law and Policy
http://epi.yale.edu/downloads
Coverage: 192 countries
Time Series: Annual since 1990
Issues: (i) The measure does not take into account the quality of the management of the protected area. The Yale team also acknowledges this and they are working towards gathering improved data.

Measure: *ENC - Dependency on Natural Capital expressed as a % of the GDP.*
Description: Based on Natural Capital accounting project of the World Bank. This measure seeks to account for the use of natural capital in national accounting by including information on the change in natural capital such as mineral resources, forest stocks etc. In this measure only those elements related to ecosystem services are counted. These are crop, pasture, forest (timber), forest (non-timber) and protected areas. Sub-surface capital such as oil, gas and mineral reserves are not included in this measure for GAIN.

Rationale: This measure captures a country's reliance on ecosystem services, which are themselves exposed to disruption by climate change.
Source: See "The Changing Wealth of Nations : Measuring Sustainable Development in the New Millennium." World Bank 2011, ISBN 978-0-8213-8554-8 (electronic). http://data.worldbank.org/sites/default/files/total_and_per_capita_wealth_of_nations.xls
Coverage: 148 countries.
Time Series: Three estimates; 1995, 2000, 2005
Issues: (i) This is a comprehensive treatment with strong academic input and institutional support but it is not widely used elsewhere probably due to its complexity. The most recent estimate appeared this year but reflects data of 2005. Although work on similar measures continues and is accelerating under the "green accounting" umbrella, it is not certain that another comparable update will occur.
(ii) With only 148 countries, this is one of the vulnerability measures with the weakest coverage.
(iii) This measure includes GDP in its calculation as it is expressed as the depreciated value of the natural capital as a percentage of the GDP – something we have tried to avoid given it can impose a double jeopardy on poor countries. However, its correlation with ln(GDP per capita) is $R^2=0.54$ with a wide scatter among the poorer countries (Fig. 6).

Measure: *ETS - Threatened Species.*
Description: Composite measure made up of (1) the percentage of mammal species recorded as threatened; (2) the percentage of plant species threatened; and (3) the number of bird species threatened. These three groups (mammals, plants and birds) represent a good, but incomplete, coverage of the state of ecosystems. Birds have to be treated differently from mammals and plants because the number of bird species within a country is difficult to determine as many are migratory over long distances and the source of the threat of extinction may arise from causes far distant from the country.
Rationale: Threats of extinction arise from many pressures currently unrelated to climate change. Further climate change is likely to exacerbate these pressures in many cases and thus this measure is an indication of the sensitivity of a country's ecosystems services to change in the future.
Source: IUCN Red Book and related data.
Coverage: 187 countries.
Time Series: Single estimate only.
Issues: (i) There is some overlap with a country's capacity to manage its natural resources.
(ii) The measure does not include species that have passed from threatened to extinct. There are data that could be used but they would have to be rescaled to be incorporated. Extinction data also raised issues of equity; for example regions recently settled by technological societies such as North America and Australia will score disproportionately high while extinctions for areas with longer settlement of this type (e.g. Europe and China) many extinction would go unrecorded.

Measure: *EIC - Engagement in International Environmental Conventions*
Description: A measure based on the country's participation in international forums, which is taken as an indicator its capacity to engage in multilateral negotiations and to reach agreement on appropriate actions internally.
Rationale: Although not a direct measure of capacity, the failure to take part in such forums is usually associated with either lack of technical capacity to deal with the issues and/or lack of political ability to reach decisions over appropriate engagement.
Source: From http://sedac.ciesin.columbia.edu/entri/index.jsp

Coverage: 198 countries

Time Series: Annual since 1995 based on the continually increasing number of conventions etc and the time lags in countries signing and ratifying the agreements.

Issues: (i) The outcome for this measure is strongly dependent on the process of selecting the agreements to be included (Table 1). We sought to include "environmental treaties" in their broadest sense while avoiding any to do with military/warfare; gross marine pollution, safety at sea and other shipping controls. We also excluded treaties directly setting up International organizations such as the World Bank etc. We also excluded agreements with less than 20 signatories.

(ii) Some agreements have a limited regional scope (e.g. dealing with Atlantic tuna). We could have excluded them, but this would have limited the list (16 out of 54 have clear regional scope of application), but many are signed by countries beyond the region (e.g those with fishing fleets in the Atlantic). Many (17 out of 54) also deal with the agreements on oceans and this may disadvantage land-locked countries, however, land-locked countries are sometimes signatories to such conventions (e.g. those relating to whaling). It could similarly be argued that some agreements are not relevant to many countries on other grounds (e.g. those to do with desertification). Thus we chose to retain a wide set of agreements rather than begin a culling process that would have reduced the list to only 10 to 20 or so.

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Urban

Measure: *UUC - Urban Concentration*

Description: Percentage of the population living in the largest city.

Rationale: A high concentration of people in one city creates challenges in adapting to climate change. The concentration suggests stressed services, few choices for displaced rural poor and vulnerability to major losses in a single extreme climate event.

Source: World Bank, World Development Indicators, EN.URB.LCTY.UR.ZS

Coverage: 183 countries

Time Series: Annual since 1995

Issues: (i) An alternative measure is the proportion of the population living in cities with a population of 1 million or more. These data are available but for far fewer countries. It would also exclude countries with populations of less than about 1 to 2 million.

Measure: *UUS - Urban Population Living in Slums*

Description: A slum household is defined as a group of individuals living under the same roof lacking one or more1 of the following conditions: Access to improved water; Access to improved sanitation; Sufficient-living area; Durability of housing (Tenure is included as a 5th element, but insufficient data is available).

Rationale: Slums impose a great challenge to successful adaptation especially in cities.

Source: UN Millennium Development Goals Data - 7.10 Proportion of urban population living in slums.

http://mdgs.un.org/unsd/mdg/Metadata.aspx?IndicatorId=0&SeriesId=710

Coverage: 87 countries in the original set but expanded to159 after assumption that wealthier countries have a default score of 0

Time Series: 1990, 1995, 2000, 2005, 2007, 2009; best for 2005

Issues: (i) This is an indirect estimate and includes some measures that overlap with those used elsewhere in the Index. However correlation analysis shows that correlations are low.

It is related to GDP/cap but still conveys useful information especially at intermediate levels of GDP/cap (Fig 7).
(ii) The assumption that wealthy countries (not estimated as part of the MDG) have no people in slums is probably technically correct by the UN MDG definition, but an underestimate in practice.

Measure: *UEX - Excess Urban Population Growth*
Description: Excess rate of population growth in urban centres compared with the population growth rate in the whole country.
Formulae:

Expected urban popn growth = Urban popn * Country Popn growth

Excess urban popn growth = (Urban Popn * Urban Popn growth – Expected urban popn growth) / Expected urban popn growth

Rationale: If the urban population is growing considerably faster than the country as a whole, this is likely to be putting additional strain on urban services and making it difficult for city managers to also consider and plan for the effects of climate change.
Source: World Bank, World Development Indicators; SP.URB.TOTL; SP.URB.GROW; SP.POP.GROW
Coverage: 186 countries
Time Series: Since 1995
Issues: None???

Measure: *UAS - Urban Access to Sanitation*
Description: % by which urban access to improved sanitation exceeds that in rural areas
Rationale: This is an indicator of how much better living conditions might be perceived to be in urban areas by rural dwellers, and thus a measure of the attractiveness of urban migration.
Source: World Bank, World Development Indicators; SH.STA.ACSN.RU; SH.STA.ACSN.UR
Coverage: 174 countries
Time Series: Since 1995
Issues: (i) A city with good sanitation in a country with relatively poor rural access will be scored as vulnerable, even though the provision of those services in the city indicated capacity. However, here the measure is being used as a measure of sensitivity. In times of crisis (e.g. disasters or economic hardship) rural dwellers are more likely to migrate to the cities making it more difficult to cope with the influx. This is a measure of sensitivity due to the potential for higher migration rates, whereas UEX above is a measure of what is being sustained currently.

Figures

Figure 1.   New Summary of the matrix of measures (in blue)

Sector	Exposure	Sensitivity	Capacity
Water	○ ◉	○ ◉	○ ◉
Food	○ ◉	○ ◉	○ ◉
Health	○ ◉	○ ◉	○ ◉
Ecosystem Services	○ ◉	○ ◉	○ ◉
Infrastructure			
Coastal	○	○	
Energy	○	○	
Transport	○	○	
Urban	○	○	
Urbanization	○	○	

New Listing of all the measures used in the Vulnerability Score of the GAIN Index

Sector		Exposure	Sensitivity	Capacity
Life Support Sectors				
Water	**Quantity**	Projected change in precipitation	Internal and external freshwater water extracted for all uses	Population with access to improved water supply
	Quality	Projected change in temperature	Mortality among under 5 yr-olds due to water-borne diseases	Population with access to improved sanitation
Food	**Quantity**	Projected change in agricultural (cereal) yield	Population living in rural areas	Agricultural capacity
	Quality	Coefficient of variation in cereal crop yields	Food import dependency	Children under 5 suffering from malnutrition

Health	**Quantity**	Estimated impact of future climate change on deaths from disease	Health workers per capita	Longevity
	Quality	Mortality due to communicable (infectious) diseases	Health expenditure derived from external resources	Maternal mortality
Ecosystem Services	**Quantity**	tbd	Ecological footprint surplus or deficit	Protection of biomes
	Quality	Dependency on natural capital derived from ecosystems	Threatened species	Engagement in multilateral environmental agreements
Infrastructure Sectors				
Coast	**Quantity**	Land less than 10m above sea-level	Population living less than 10m above sea-level	Measured on the Readiness Axis
Energy	**Quantity**	Population with access to reliable electricity	Energy at risk	
Transport	**Quantity**	Frequency of floods per unit area	Percentage of roads paved	
Urban	**Quantity**	Urban concentration	Population in urban slums	
Urbanization	**Quantity**	Excess urban population growth	Increased access to sanitation in urban areas	

Figure 2. The relationship between the Total Ecosystem Services Vulnerability component to GDP per capita (here Ln(GDP/cap)). Although there is a negative relationship (poor countries are more vulnerable on this score, R^2=0.34), there is a wide dispersal across all income levels.
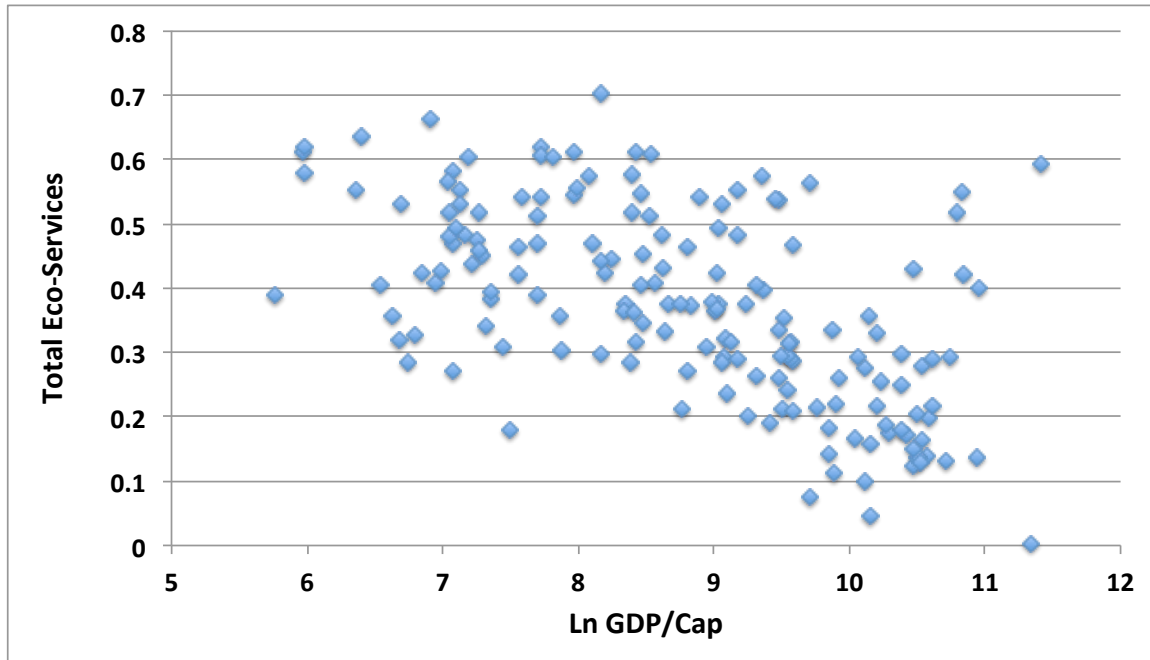
Figure 3. Country rankings with respect to the new measures and the effect of the new measures on vulnerability rankings[1]. The background colours in the rightmost column of ranking data show reduced or no change in vulnerability rank (green), increased vulnerability (pink) and new to the list (yellow).

Lowest Vulnerability		Ecosystem Services Vuln Score		Urban Vuln Score	Original 2011 Vulnerability Ranks	New Expanded Vulnerability Ranks
1	Luxembourg	0.00	Germany	0.00	Denmark	Germany
2	Iceland	0.13	Bahrain	0.02	France	Luxembourg
3	Finland	0.13	Czech Republic	0.03	Czech Republic	Switzerland
4	Sweden	0.13	Belgium	0.03	Switzerland	France
5	Switzerland	0.13	Sweden	0.04	Germany	Czech Republic
6	Norway	0.14	United Kingdom	0.04	Poland	Norway
7	Germany	0.14	Kazakhstan	0.04	Norway	Poland
8	Malta	0.14	Luxembourg	0.04	Ireland	Denmark
9	Austria	0.14	Bulgaria	0.04	Luxembourg	United Kingdom
10	United Kingdom	0.15	Ukraine	0.04	United Kingdom	Sweden
11	Poland	0.15	Switzerland	0.05	Austria	Italy
12	Trinidad and Tobago	0.16	Hungary	0.05	Croatia	Croatia
13	Estonia	0.16	Brunei Darussalam	0.05	Finland	Austria
14	Latvia	0.17	Canada	0.06	Slovenia	Finland
15	Canada	0.17	Norway	0.06	Netherlands	Slovenia
16	France	0.18	Sri Lanka	0.06	United States	Australia
17	Greece	0.18	Belarus	0.06	Italy	Ireland
18	Italy	0.18	Slovenia	0.06	Uruguay	Slovakia
19	Czech Republic	0.18	Australia	0.06	Argentina	United States
20	Cyprus	0.19	Qatar	0.06	Slovakia	Bulgaria
Highest Vulnerability						
20	Korea, Dem People's Rep	0.66	Moldova, Republic of	0.59	Uganda	Yemen
19	Moldova, Republic of	0.66	Bhutan	0.59	Mauritania	Madagascar
18	Vanuatu	0.66	Mozambique	0.60	Micronesia FS	Laos
17	Viet Nam	0.67	Mongolia	0.61	Tanzania	Zambia
16	Comoros	0.67	Burkina Faso	0.64	Rwanda	Togo
15	Papua New Guinea	0.68	Lesotho	0.64	Togo	Marshall Islands
14	Kyrgyzstan	0.69	Togo	0.64	Burkina Faso	Mozambique
13	Zimbabwe	0.69	Marshall Islands	0.64	Mali	Mali
12	Timor-Leste	0.70	Yemen	0.65	Liberia	Niger
11	Uzbekistan	0.71	Angola	0.67	Zambia	Angola
10	Serbia	0.71	Djibouti	0.68	Somalia	Liberia
9	Cuba	0.72	Tonga	0.68	Niger	Ethiopia
8	Madagascar	0.73	Somalia	0.68	Angola	Solomon Islands
7	Iraq	0.74	Eritrea	0.69	Mozambique	Central African Rep
6	Solomon Islands	0.75	Haiti	0.71	Sierra Leone	Micronesia FS
5	Palau	0.79	Guinea-Bissau	0.72	Chad	Chad
4	Samoa	0.79	Solomon Islands	0.75	Ethiopia	Sierra Leone
3	Micronesia, Fed States	0.83	Lao People's Dem Rep	0.86	Central African Rep	Somalia
2	Sao Tome and Principe	0.86	Cambodia	0.89	Burundi	Burundi
1	Fiji	0.86	Palau	0.98	Afghanistan	Afghanistan

[1] Note that this list of the "Original" differs slightly from that shown on the web as the web used different rules for missing data for inclusion in the list. However, it does not change the basic conclusions.

Figure 4. The new measures increase the average vulnerability score marginally from 0.330 to 0.349 with middle vulnerability countries tending to increase in vulnerability and those with high or low vulnerability being more likely to fall.
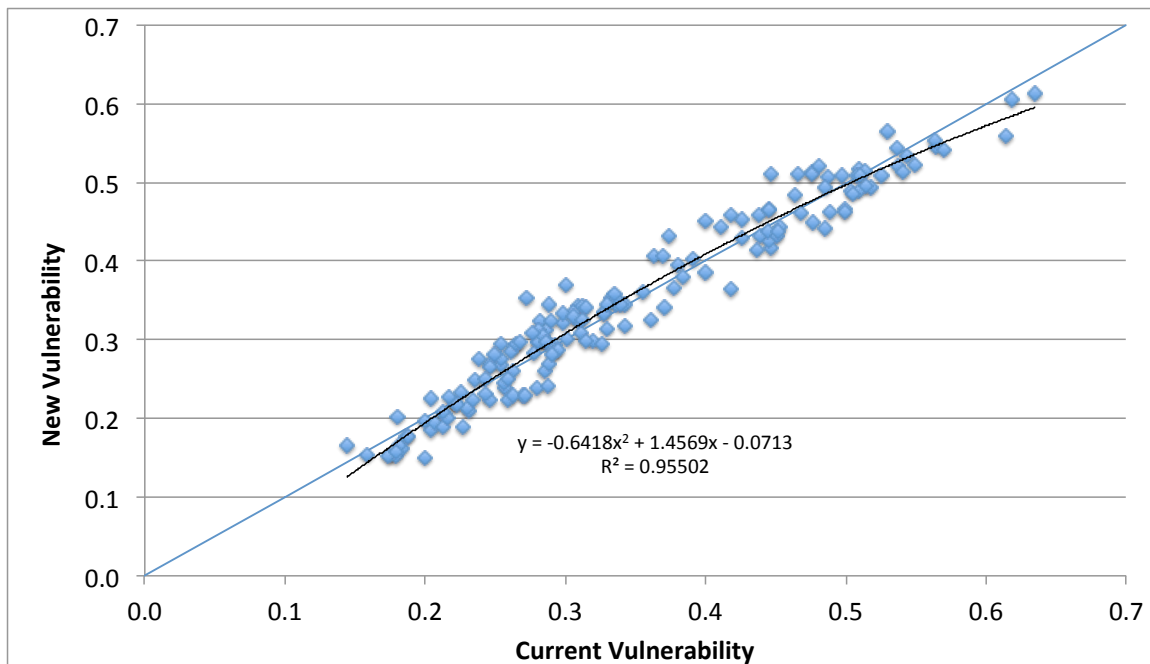

$y = -0.6418x^2 + 1.4569x - 0.0713$
$R^2 = 0.95502$

Figure 5. No correlation between the measures based on Natural Capital Dependency and the Net Ecological Footprint scores.
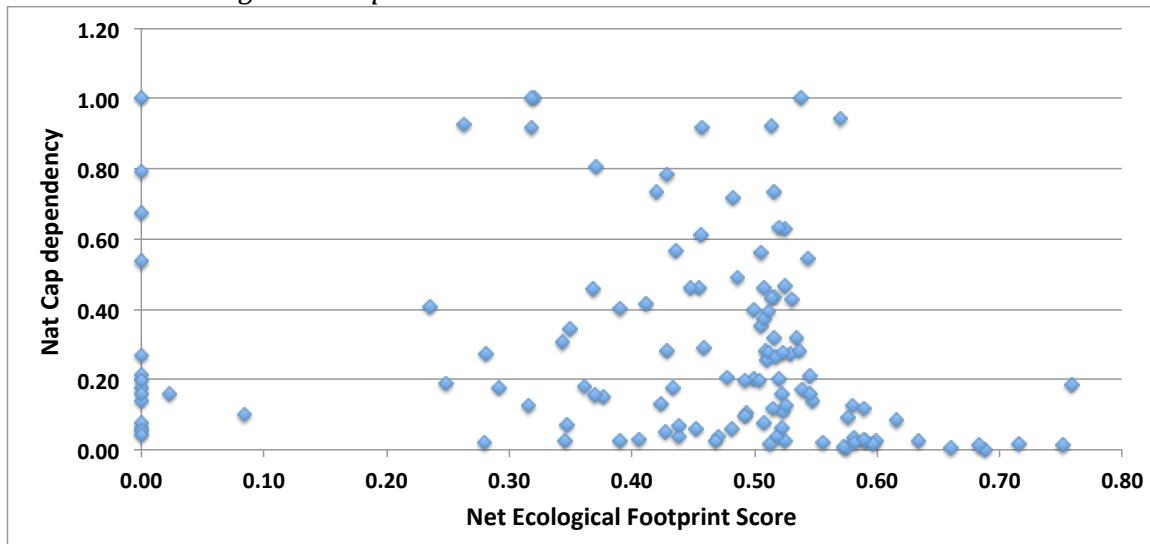
Figure 6. Relationship between Dependency on (Ecosystem) Natural Capital and GDP per capita. There is a negative relationship (R^2=0.54) but there is a wide scatter among the poorer countries, while wealthier countries (above about $5000 to $8000 per year) tend to be less dependent on the ecosystem component of natural capital. Many of the wealthier countries are mineral and oil rich states and are thus dependent on natural capital in its full definition.
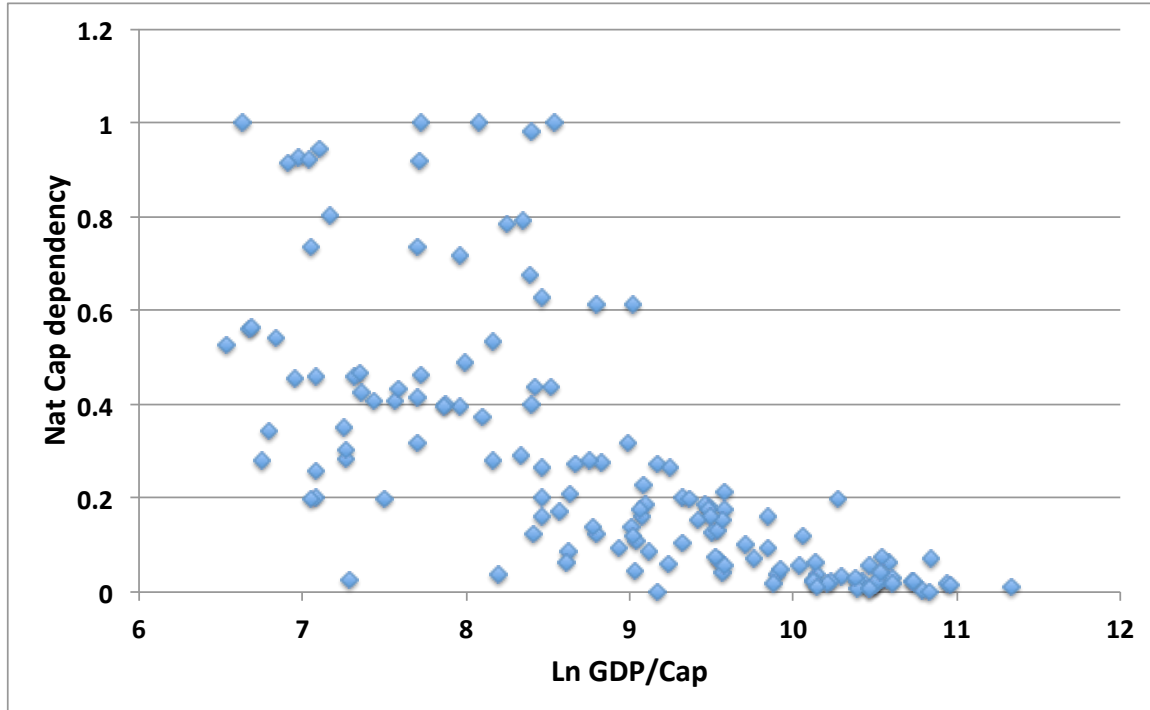
Figure 7. Proportion of the population living in slums is related to wealth, but there is nevertheless a wide scatter among countries of intermediate wealth per capita.
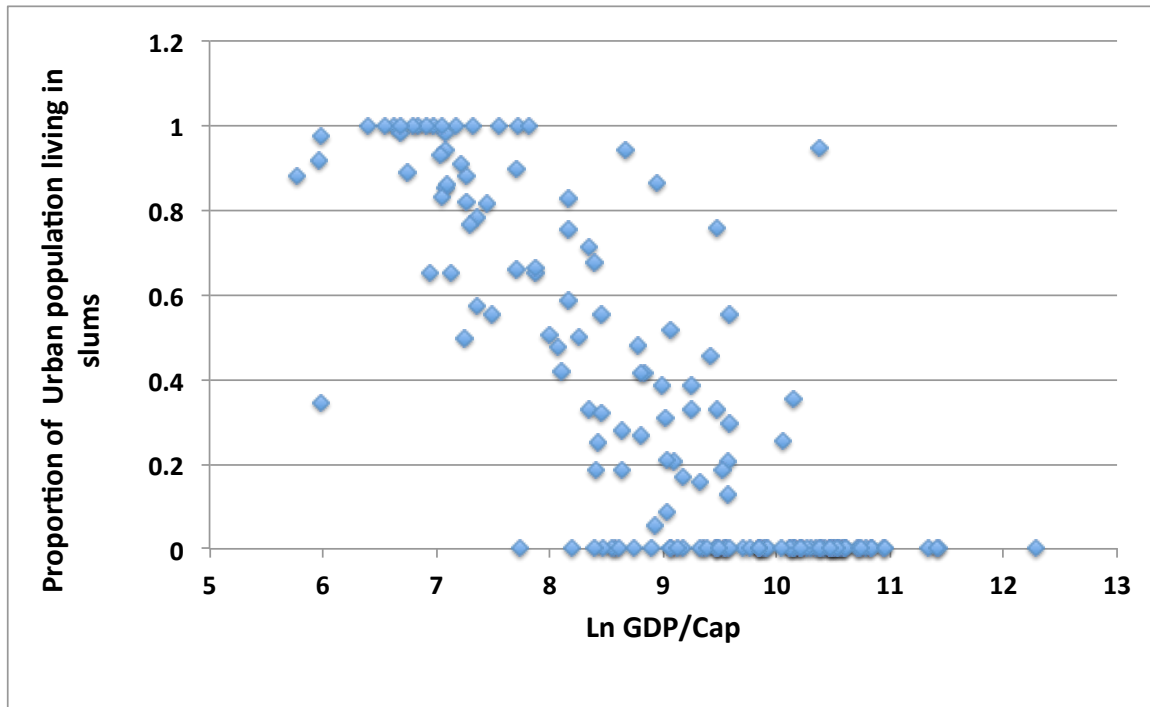
Table 1. List of international agreements used in EPB – Engagement in Environmental Treaties

List of international agreements used in *EPB – Engagement in Environmental Treaties*

1. African Convention on the Conservation of Nature and Natural Resources
2. Agreement for the Establishment of a General Fisheries Commission for the Mediterranean
3. Agreement for the Establishment of the Asia-Pacific Fishery Commission
4. Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stoc
5. Agreement on the Conservation of African-Eurasian Migratory Waterbirds
6. Amendment of the Plant Protection Agreement for the Asia and Pacific Region
7. Amendment to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Art.XI)
8. Amendment to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Art.XXI)
9. Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer
10. Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer
11. Amendments to Articles 6 and 7 of the Convention on Wetlands of International Importance especially as Waterfowl H
12. Convention concerning the Protection of the World Cultural and Natural Heritage
13. Convention for the Establishment of the European and Mediterranean Plant Protection Organisation
14. Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region
15. Convention for the Protection of the Mediterranean Sea against Pollution
16. Convention for the Protection of the Ozone Layer
17. Convention for the Regulation of Whaling
18. Convention on Biological Diversity
19. Convention on Environmental Impact Assessment in a Transboundary Context
20. Convention on Fishing and Conservation of the Living Resources of the High Seas
21. Convention on International Trade in Endangered Species of Wild Fauna and Flora
22. Convention on Long-Range Transboundary Air Pollution
23. Convention on Wetlands of International Importance especially as Waterfowl Habitat
24. Convention on the Conservation of Antarctic Marine Living Resources
25. Convention on the Conservation of European Wildlife and Natural Habitats
26. Convention on the Conservation of Migratory Species of Wild Animals
27. Convention on the Continental Shelf
28. Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal
29. Convention on the High Seas
30. Convention on the International Maritime Organization
31. Convention on the Protection and Use of Transboundary Watercourses and International Lakes
32. Convention on the Territorial Sea and the Contiguous Zone
33. International Convention for the Conservation of Atlantic Tunas
34. International Convention for the Protection of New Varieties of Plants as amended on 23.10.1978
35. International Convention for the Regulation of Whaling
36. International Convention to Combat Desertification in those Countries Experiencing Serious Drought and or Desertifica
37. International Plant Protection Convention
38. International Plant Protection Convention (1979 Revised Text)
39. International Tropical Timber Agreement
40. International Tropical Timber Agreement
41. Plant Protection Agreement for the Asia and Pacific Region
42. Protocol Relating to Modification of the International Convention for the Conservation of Atlantic Tunas
43. Protocol concerning Mediterranean Specially Protected Areas
44. Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources
45. Protocol on Substances that Deplete the Ozone Layer
46. Protocol to amend the Convention on Wetlands of International Importance especially as Waterfowl Habitat
47. Protocol to the Antarctic Treaty on Environmental Protection
48. Protocol to the Convention on Long-Range Transboundary Air Pollution concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes

49. Protocol to the Convention on Long-Range Transboundary Air Pollution on further Reduction of Sulphur Emissions
50. Protocol to the Convention on Long-range Transboundary Air Pollution on Long-Term Financing of Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EME
51. Protocol to the International Convention for the Regulation of Whaling
52. The Antarctic Treaty
53. United Nations Convention on the Law of the Sea
54. United Nations Framework Convention on Climate Change