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The future value of ecosystem services: Global scenarios and national implications

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ABSTRACT

We estimated the future value of ecosystem services in monetary units for 4 alternative global land use and management scenarios based on the Great Transition Initiative (GTI) scenarios to the year 2050. We used previous estimates of the per biome values of ecosystem services in 2011 as the basis for comparison. We mapped projected land-use for 16 biomes at 1 km^2 resolution globally for each scenario. This, combined with differences in land management for each scenario, created estimates of global ecosystem services values that also allowed for examinations of individual countries. Results show that under different scenarios the global value of ecosystem services can decline by $51 trillion/yr or increase by USD $30 trillion/yr. In addition to the global values, we report totals for all countries and maps for a few example countries. Results show that adopting a set of policies similar to those required to achieve the UN Sustainable Development Goals, would greatly enhance ecosystem services, human wellbeing and sustainability.

1. Introduction

Ecosystem services are a major contributor to sustainable human wellbeing. Between 1997 and 2011, the global value of these services has decreased by an estimated USD 20 trillion/yr. due to land use change (Costanza et al., 2014). We synthesized three existing sets of scenarios (Raskin et al., 2002; Bateman et al., 2013; Costanza et al., 2015) to develop and evaluate the future value of global ecosystem services under four alternative land-use and management scenarios (Table 1). The scenarios are based around the four 'Great Transition Initiative' (GTI) archetypes (Hunt et al., 2012) created by Raskin et al. (2002). They provide a range of plausible futures that incorporate different policies and world views and their effects on a range of issues, including climate change, economics, overall wellbeing, and land and water use and management (Fig. 1). A large number of studies use a broad range of future scenarios. Van Vuuren et al. (2012) surveyed these studies and concluded that: "Comparison of these studies shows that there is actually a limited set of scenario families that form the basis of many scenarios used in different environmental assessments." This is a conclusion shared by Hunt et al. (2012) and Costanza et al. (2015). Similar, broad range land-use and social-economic scenarios, within these archetypes, are also being used by the IPCC (O'Neill et al., 2017; Popp et al., 2017; Riahi et al., 2017). The GTI scenarios, used in this paper, fit this set of families or 'archetypes' and include aggregate land use projections tied to the scenarios. These scenarios are best thought of as 'exploratory' (IPBES, 2016) in that they represent different plausible futures based on storylines, as opposed to 'target-seeking', 'policy-screening', or 'retrospective' scenarios.

We estimated the implications of these scenarios and their land use and management assumptions for the value of ecosystem services to 2050 (Fig. 2).

The GTI scenarios are described in more detail later, but in summary are:

1. **Market Forces (MF):** an economic and population growth archetype based on neoliberal free market assumptions;
2. **Fortress World (FW):** an archetype in which nations and the world become more fragmented, inequitable, and head towards temporary or permanent social collapse;
3. **Policy Reform (PR):** a continuing economic growth archetype, but with discipline/restraint/regulation based on assumptions about the need for government intervention and effective policy; and,

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Table 1
This table shows the 12 scenarios that were combined from 3 different sources to make the four future scenarios used in this paper. It also shows the characteristics and variable of these four scenarios.

ELD Scenarios	1997	2011	1. MF	2. FW	3. PR	4. GT
Great Transition Initiative (GTI)			Market Forces	Fortress World	Policy Reform	Great Transition
Costanza et al. (2014)			Free Enterprise	Strong Individualism	Coordinated Action	Community Well Being
Bateman et al. (2013)			Focus on Market Growth	Maintain Current Practices	Green and Pleasant Land	Conservation Fully Implemented
Population (e9)	5.9	7	9.08	9.53	8.68	8.08
Urban pop (e9)	2.75	3.5	6.25	6.57	5.99	5.57
Rural pop (e9)	3.15	3.5	2.83	2.96	2.69	2.51
Global GDP (e12 $2007)	53	87	188	162	180	170
Inequality (Richest 10%/Poorest 10%)		16	29.4	53	14.9	7.1
Urban land (e6 ha)	332	350	554	675	490	397
Cropland (e6 ha)	1400	1672	1757	1782	1733	1676
Forest (e6 ha)	4855	4261	3450	3541	3989	4313
Grass/Rangeland (e6 ha)	3898	4418	3991	3696	4219	4483
Desert (e6 ha)	1925	2159	3396	3494	2427	1924

Fig. 1. The two axes on which the four scenarios are laid out on. This is a commonly used method in developing scenarios. The horizontal axis shows the range between giving priority to the individual or collective (community) interests. The vertical axis distinguishes between a focus on GDP growth and materialistic consumption versus a focus on the well-being of humans and the environment.

4. **Great Transition (GT):** a transformation archetype based on assumptions about limits to conventional GDP growth and more focus on environmental and social wellbeing and sustainability.

The ecosystem services in these four scenarios were estimated globally and we also report the implications for selected countries, including Australia, Brazil, China, Germany, India, South Africa, and the United States. These countries were chosen as examples from each of the continents (two from Asia), excluding Antarctica. Results for all countries are included in Supplementary information (Table S1).

2. Global value of ecosystem goods and services

Ecosystems provide the life support system of our planet (Costanza et al., 1997, 2014; Millennium Ecosystem Assessment (MEA), 2005). However, over the past several decades, the goods and services[1] that they provide have been significantly degraded (Sutton et al., 2016). In 2011, the total value of global ecosystem services were estimated to be USD 125 trillion/yr (Costanza et al., 2014). This value was estimated to be a decrease of USD 20.2 trillion/yr from 1997 due to land use and management changes[2] (Costanza et al., 1997, 2014) – a trend which is currently continuing. Interest in ecosystem services in both the research and policy communities is growing rapidly (Balvanera et al., 2012; Braat and de Groot, 2012; Costanza and Kubiszewski, 2012; Egoh et al., 2012; Maes et al., 2012; Molnar and Kubiszewski, 2012; Pittock et al., 2012).

Before the last US presidential election, a memo from President Obama to US Federal agencies directed them to incorporate ecosystem services into their planning, investment, and regulations[3]. The memo also stated that such consideration of ecosystem services could occur "through a range of qualitative and quantitative methods to identify and characterize ecosystem services, affected communities' needs for those services, metrics for changes to those services and, where appropriate, monetary or nonmonetary values for those services" (Donovan et al., 2015). The status of this memo under the new administration is, of course, uncertain. But several other countries have also begun to incorporate ecosystem services in their policies. The European Union (EU) has mandated all member countries within the EU to produce national ecosystem service assessments to then be used in policy and decision-making. On the international level, several other initiatives, networks, and platforms

[1] For simplicity, we refer to all the benefits that ecosystems provide to humans as "ecosystem services," recognizing that they cover a large range of goods and services, including provisioning, regulating, cultural, and supporting services. See references 6–8 for more detailed descriptions.

[2] Changes in values result from both changes in supply and changes in valuation and valuation methodology. Costanza et al. (2014) included an analysis of both of these effects. Here we list only the results using the most recent values and methods.

[3] https://www.whitehouse.gov/blog/2015/10/07/incorporating-natural-infrastructure-and-ecosystem-services-federal-decision-making.

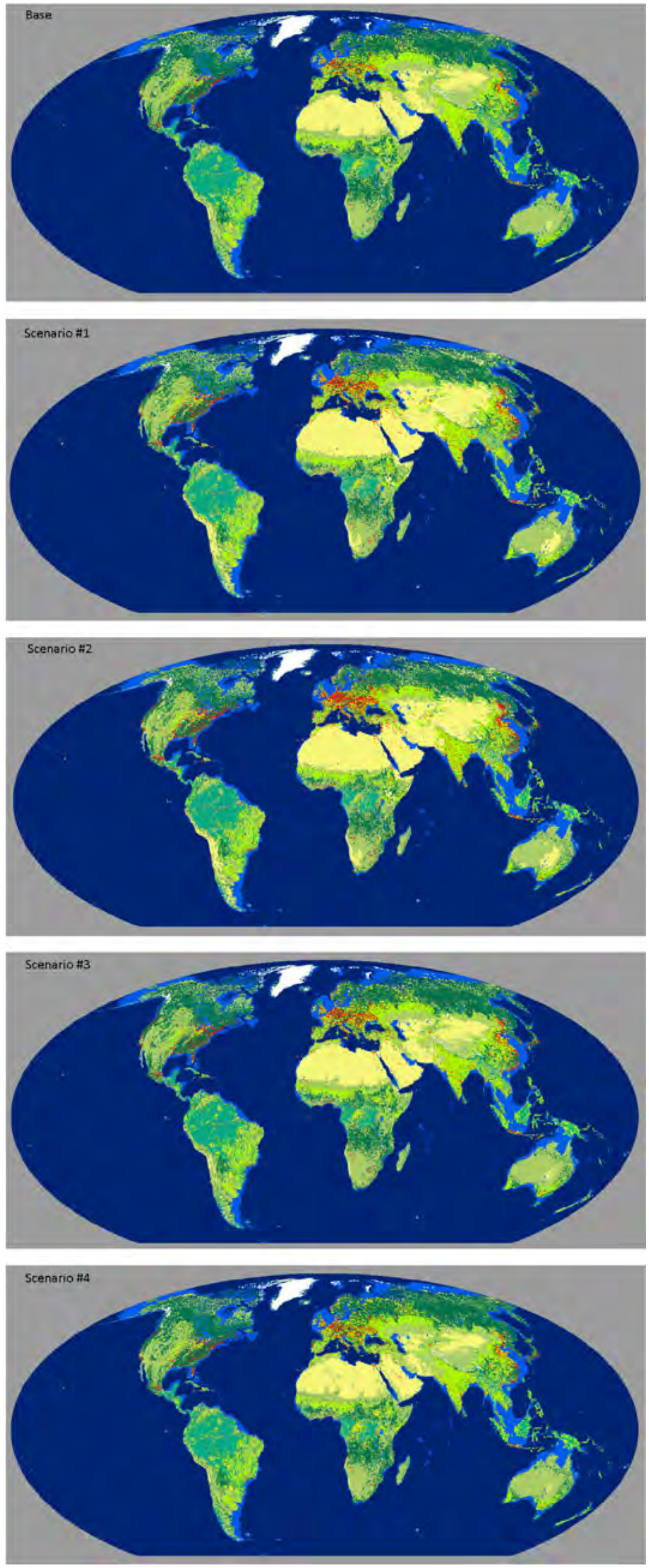

Fig. 2. Five global maps showing the 2011 base ecosystem services value (labeled Base) and the global ecosystem services values for each of the scenarios (labeled Scenario #1–4).

are underway. These include, but are not limited to, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which has been established by the UN as an entity analogous in structure and function to the IPCC, and the international Ecosystem Services Partnership (ESP), which has been established to coordinate and facilitate exchange of information about global efforts, projects, scholars, and practitioners.

2.1. Valuation of ecosystem services

Valuing ecosystems and the goods and services they provide has a long history (Westman, 1977; Costanza et al., 1997; Baveye et al., 2013). One key use of valuation has been to allow ecosystems to be explicitly considered in decisions that involve trade-offs (Farber et al., 2002). Trade-offs involving ecosystem services imply either implicit or explicit valuation (Costanza et al., 1997). Explicit valuation allows the units of all the elements to be expressed in the same common denominator to allow direct comparison of the trade-offs. Often, this is most easily and usefully done using monetary units, but other units such as time, energy, or land area are also possible (Wackernagel and Rees, 1996; Rees, 2006) and a pluralistic, integrated, approach to valuation is obviously preferred (Costanza, 2000; Jacobs et al., 2016; Pascual et al., 2017).

However, expressing values in monetary units does not imply privatization or market exchanges (Costanza, 2006; McCauley, 2006; Costanza et al., 2014). Most ecosystem services are non-rival and/or non-excludable, and therefore fit poorly into markets (Kubiszewski et al., 2010). Additionally, ecosystem service values often relate to non-market use or non-use values rather than market or psudo-market exchange values (Daly, 1998). We hasten to add that valuation of ecosystem services in monetary units is not in conflict with other approaches to considering their importance, but represents an additional piece of information that can complement other approaches.

This paper investigates alternative and plausible global land-use and management scenarios to the year 2050, which could either accelerate or reverse land degradation and the resulting impacts of these scenarios on the estimated value of ecosystem services.

3. Scenario planning

Scenario analysis or scenario planning is defined as a ‘structured process of exploring and evaluating alternative futures’ (Costanza et al., 2015). Scenarios combine influential and uncertain drivers, that have low controllability, into storylines of the future (O'Brien, 2000). Ultimately, the goal of scenario planning is to illustrate the consequences of these drivers and policy options, reveal potential tipping points (Lenton et al., 2008), and inform and improve decisions. Unlike forecasting, projections, and predictions, exploratory scenarios explore *plausible* rather than *probable* futures (Peterson et al., 2003).

Scenario planning has become an important way to inform decision-making incorporating a whole-system perspective under uncertainty (Gallopín et al., 1997; Department of Trade and Industry (DTI), 2003). Scenarios have been used at all scales, from individual corporations to communities to global (Costanza et al., 2015). This paper uses the GTI scenarios as a basis since they have been widely vetted and the scenarios have been found to be typical of many other scenario studies (Hunt et al., 2012). The GTI scenarios were created by an international network of scholars, using expert opinion, models and regional analyses (McGrail, 2011). They also developed global land use projections for each scenario, which we incorporated.

4. Methods

4.1. Global land use change scenarios and national implications

The scenarios can be arranged across two broad axes as shown in Fig. 1. One axis is a focus on individuals versus the community. The second axis is a focus on conventional GDP growth versus wellbeing more broadly. These two axes create 4 possible scenarios.

Detailed Great Transition Initiative (GTI) scenarios exist for both the global system and several regions.[4] Brief narrative descriptions of each scenario, extracted directly from the GTI website, are reproduced here:

Market Forces: The *Market Forces* scenario is a story of a market-driven world in the 21st century in which demographic, economic, environmental and technological trends unfold without major surprise relative to (sic) unfolding trends. Continuity, globalization and convergence are key characteristics of world development – institutions gradually adjust without major ruptures, international economic integration proceeds apace and the socioeconomic patterns of poor regions converge slowly toward the development model of the rich regions. Despite economic growth, extreme income disparity between rich and poor countries, and between the rich and poor within countries, remains a critical social trend. Environmental transformation and degradation are a progressively more significant factor in global affairs.

Fortress World: The *Fortress World* scenario is a variant of a broader class of *Barbarization* scenarios, in the hierarchy of the Global Scenario Group (Gallopín et al., 1997). *Barbarization* scenarios envision the grim possibility that the social, economic and moral underpinnings of civilization deteriorate, as emerging problems overwhelm the coping capacity of both markets and policy reforms. The *Fortress World* variant of the Barbarization story features an authoritarian response to the threat of breakdown. Ensconced in protected enclaves, elites safeguard their privilege by controlling an impoverished majority and managing critical natural resources, while outside the fortress there is repression, environmental destruction and misery.

Policy Reform: The *Policy Reform* scenario envisions the emergence of strong political will for taking harmonized and rapid action to ensure a successful transition to a more equitable and environmentally resilient future. Rather than a projection into the future, *Policy Reform* scenario is a normative scenario constructed as a backcast *from* the future. It is designed to achieve a set of future sustainability goals. The analytical task is to identify plausible development pathways for reaching that end-point. Thus, the *Policy Reform* scenario explores the requirements for simultaneously achieving social and environmental sustainability goals under high economic growth conditions similar to those of *Market Forces*.

Great Transition: The *Great Transition* scenario explores visionary solutions to the sustainability challenge, including new socioeconomic arrangements and fundamental changes in values. This scenario depicts a transition to a society that preserves natural systems, provides high levels of welfare through material sufficiency and equitable distribution, and enjoys a strong sense of local solidarity.

Each of these scenarios have been produced and vetted by a large network of scholars and have been used as archetypes for a range of other scenario planning studies (Raskin et al., 2002;

[4] www.greattransition.org/explore/scenarios

Table 2
Changes in area, unit values, and aggregate global flow values from 1997 to 2011 for the four future scenarios to the year 2050. The green section labelled Area (e6 ha) shows the area changes from 2011 areas in millions of hectares. The red area labelled Unit Values (USD $2007/ha/yr) shows the unit values used in each of the four scenarios for every biome. The final blue section shows the total global annual value for each biome and the total annual ecosystem service value for all ecosystem services globally in each scenario. The colours of the numbers indicate: black values are values that have remained constant, green are values that have increased, red are values that have decreased from the 2011 values.

Biome	Area (e6 ha)					% Change	-0.1	-0.2	0	0.2	Total Annual Flow of Eco-Services Values (e12 2007$/yr)				
						Unit Values ($2007/ha/yr)									
		Scenarios to 2050				($/ha)	Scenarios to 2050					Scenarios to 2050			
	2011	1. MF	2. FW	3. PR	4. GT	2011	1. MF	2. FW	3. PR	4. GT	2011	1. MF	2. FW	3. PR	4. GT
Marine	**36,302**	**36,302**	**36,302**	**36,302**	**36,302**	**1,368**	**1,231**	**1,094**	**1,368**	**1,642**	**49.7**	**38.0**	**32.5**	**49.7**	**62.3**
Open Ocean	33,200	33,200	33,200	33,200	33,200	660	594	528	660	792	21.9	19.7	17.5	21.9	26.3
Coastal	3,102	3,102	3,102	3,102	3,102	8,944	8,050	7,155	8,944	10,733	27.7	18.3	15.0	27.7	36.0
Estuaries	180	180	180	180	180	28,916	26,024	23,133	28,916	34,699	5.2	4.7	4.2	5.2	6.2
Algae Beds/Seagras	234	257	262	234	227	28,916	26,024	23,133	28,916	34,699	6.8	6.7	6.1	6.8	7.9
Coral Reefs	28	5	0	28	35	352,249	317,024	281,799	352,249	422,699	9.9	1.6	0.0	9.9	14.8
Shelf	2,660	2,660	2,660	2,660	2,660	2,222	2,000	1,777	2,222	2,666	5.9	5.3	4.7	5.9	7.1
Terrestrial	**14,822**	**14,822**	**14,823**	**14,822**	**14,822**	**4,901**	**4,411**	**3,921**	**4,901**	**5,881**	**72.0**	**49.3**	**38.8**	**72.3**	**90.0**
Forest	4,225	3,426	3,574	4,037	4,269	3,800	3,420	3,040	3,800	4,560	16.1	11.8	11.0	15.4	19.3
Tropical	1,255	1,070	1,106	1,206	1,211	5,382	4,844	4,306	5,382	6,458	6.8	5.2	4.8	6.5	7.8
Temperate/Boreal	2,970	2,356	2,468	2,831	3,058	3,137	2,823	2,510	3,137	3,764	9.3	6.7	6.2	8.9	11.5
Grass/Rangelands	4,414	3,986	3,695	4,201	4,478	4,166	3,749	3,333	4,166	4,999	18.4	14.9	12.3	17.5	22.4
Wetlands	189	76	24	226	289	140,174	126,157	112,139	140,174	168,209	23.2	8.0	1.8	24.0	30.7
Tidal Marsh/Mangro	109	41	10	108	108	193,843	174,459	155,074	193,843	232,612	21.1	7.2	1.6	20.9	25.1
Swamps/Floodplain	80	35	14	118	181	25,681	23,113	20,545	25,681	30,817	2.1	0.8	0.3	3.0	5.6
Lakes/Rivers	220	220	220	220	220	12,512	11,261	10,010	12,512	15,014	2.8	2.5	2.2	2.8	3.3
Desert	1,690	2,737	2,791	1,871	1,436	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Tundra	433	433	433	431	424	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Ice/Rock	1,640	1,640	1,640	1,640	1,640	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Cropland	1,664	1,749	1,777	1,710	1,670	5,567	5,010	4,454	5,567	6,680	9.3	8.8	7.9	9.5	11.2
Urban	347	555	669	486	396	6,661	5,995	5,329	6,661	7,993	2.3	3.3	3.6	3.2	3.2
Total	**51,124**	**51,124**	**51,125**	**51,124**	**51,124**						**121.6**	**87.3**	**71.3**	**122.0**	**152.3**

Hunt et al., 2012; Costanza et al., 2015). They incorporate a range of worldviews and policies, and the impacts of these on the entire, integrated system, including population, energy use, equity, environmental change, and climate change. For our purposes in this study, we utilized the fact that the GTI scenarios also included impacts on land use and management (Fig. 2). The interactive web tool, Futures in Motion, on the GTI website was used to derive estimates of land use change (urban, cropland, forest, grassland, desert), population, GDP, and other variables such as inequality and GDP for these four future scenarios to the year 2050[5] (Table 1). Minor differences can be seen between the land use changes derived from the GTI Futures in Motion site (Table 1) and the ones used in this paper (Table 2) due to adjustments needed to accommodate land use types not considered by the GTI, to balance global totals, and to be consistent with previous estimates. For example, the GTI scenarios did not include changes in wetlands or marine systems. We know that wetlands and coral reefs are very important for ecosystem services provision (Costanza et al., 1997, 2014) and incorporated other sources for estimating their changes in each scenario. For the MF and FW scenarios we assumed that past trends in wetland and coral reef loss seen between 1997 and 2011 would continue (Costanza et al., 1997, 2014; Millennium Ecosystem Assessment (MEA), 2005). For the PR scenario we assumed a government policy of 'no net loss' implying no change in wetland area., For the GT scenario we assumed an aspirational wetland and coral reef restoration policy based on achieving wetland and coral reef areas similar to those in 2000 (Mitsch and Day, 2006; Gascoigne et al., 2011; Costanza et al., 2014). These changes are described in more detail later in the section on results. We also estimated the sensitivity of our conclusions to changes in these assumptions.

Climate change was incorporated into the scenarios through the assumptions incorporated in each of the GTI scenarios, including changes in ecosystem service unit values[6] described below. For example, in the GT scenario, climate change is assumed to have been addressed, ecosystems are preserved, and their management and health is improved. In the PR scenario, climate change is addressed to some extent, ecosystem management is improved to some extent, but the focus is still on development and economic growth. In the MF scenario, climate change is not a major concern and is allowed to continue unabated. Development and economic growth progress globally at a rate similar to today – i.e. the "business as usual" scenario, but ecosystem services are degraded. In the FW scenario, there is little interest or concern for climate change. The atmosphere and the world's ecosystems are depleted to the extent required to allow the privileged few to live materially enriched lives.

The GTI scenarios are integrated illustrations of the whole system that might result if the assumed policy choices are made. They recognize that in complex, highly interconnected human and natural systems, it is not possible to change just one aspect of the system (Beddoe et al., 2009). This means that isolating individual policies, like those around climate change, from other policy effects, is counter to the idea of integrated scenarios. For example, in order to adequately address climate change, as assumed in the GT scenario, a whole suite of new goals and policy changes would have to be adopted, including massive conversion to renewable energy, increased emphasis on equitable distribution of wealth and resources, enhanced recognition of the value of ecosystems, and many others. It turns out, that the goals emphasized in the GT scenario are very similar to the 17 Sustainable Development Goals (SDGs) recently adopted by all 193 United Nation member states. Thus, our estimates of the change in ecosystem service values for the GT scenario can be interpreted as the implications of the SDGs being met to a large degree. On the other hand, the MF scenario is based on "business-as-usual" with continued use of fossil

[5] www.tellus.org/results/results_World.html

[6] Unit value: the value of a hectare of an ecosystem per year, in monetary units.

Table 3
Total global annual flow of ecosystem services values when unit values are kept at those used in 2011 but area extents for each biome are adjusted from 2011 for the four future scenarios to the year 2050. The green section labelled Area (e6 ha) shows the area changes from 2011 areas in millions of hectares. The orange section shows the total values (trillion USD 2007 $/yr) if the unit values were kept the same as used in the 2011 base study.

Biome	Area (e6 ha)					% Change Unit Val ($/ha)	No change in unit values (e12 2007$/yr)			
		Scenarios to 2050					Scenarios to 2050			
	2011	1. MF	2. FW	3. PR	4. GT	2011	1. MF	2. FW	3. PR	4. GT
Marine	**36,302**	**36,302**	**36,302**	**36,302**	**36,302**	**1,368**	**42.2**	**40.6**	**49.7**	**51.9**
Open Ocean	33,200	33,200	33,200	33,200	33,200	660	21.9	21.9	21.9	21.9
Coastal	3,102	3,102	3,102	3,102	3,102	8,944	20.3	18.7	27.7	30.0
Estuaries	180	180	180	180	180	28,916	5.2	5.2	5.2	5.2
Algae Beds/Seagras	234	257	262	234	227	28,916	7.4	7.6	6.8	6.6
Coral Reefs	28	5	0	28	35	352,249	1.8	0.0	9.9	12.3
Shelf	2,660	2,660	2,660	2,660	2,660	2,222	5.9	5.9	5.9	5.9
Terrestrial	**14,822**	**14,822**	**14,823**	**14,822**	**14,822**	**4,901**	**54.8**	**48.5**	**72.3**	**75.0**
Forest	4,225	3,426	3,574	4,037	4,269	3,800	13.1	13.7	15.4	16.1
Tropical	1,255	1,070	1,106	1,206	1,211	5,382	5.8	6.0	6.5	6.5
Temperate/Boreal	2,970	2,356	2,468	2,831	3,058	3,137	7.4	7.7	8.9	9.6
Grass/Rangelands	4,414	3,986	3,695	4,201	4,478	4,166	16.6	15.4	17.5	18.7
Wetlands	189	76	24	226	289	140,174	8.8	2.3	24.0	25.6
Tidal Marsh/Mangro	109	41	10	108	108	193,843	7.9	1.9	20.9	20.9
Swamps/Floodplain	80	35	14	118	181	25,681	0.9	0.4	3.0	4.6
Lakes/Rivers	220	220	220	220	220	12,512	2.8	2.8	2.8	2.8
Desert	1,690	2,737	2,791	1,871	1,436	0	0.0	0.0	0.0	0.0
Tundra	433	433	433	431	424	0	0.0	0.0	0.0	0.0
Ice/Rock	1,640	1,640	1,640	1,640	1,640	0	0.0	0.0	0.0	0.0
Cropland	1,664	1,749	1,777	1,710	1,670	5,567	9.7	9.9	9.5	9.3
Urban	347	555	669	486	396	6,661	3.7	4.5	3.2	2.6
Total	**51,124**	**51,124**	**51,125**	**51,124**	**51,124**		**97.0**	**89.1**	**122.0**	**127.0**

fuels, growing inequality, persistent depletion of natural capital, and the climate implications that entails. In this scenario, most of the SDGs would not be met.

4.2. Unit value changes in the scenarios

Changes in global value of ecosystem services in these scenarios were estimated to be due to two factors: 1) change in area covered by each ecosystem type; and 2) change in the "unit value" – the aggregate value of all the marketed and non-marketed ecosystem services per ha per year of each ecosystem type due to degradation or restoration (see Table 2). The unit values change depending on management policies of the land and water. These effects were separated out by evaluating the scenarios in two ways: a) using the 2011 unit values estimated by Costanza et al. (2014) and only changing land use; and b) changing both unit values and land use. The 2011 unit values were averages of literature values that were vetted and carefully selected as part of The Economics of Ecosystems and Biodiversity (TEEB) initiative (Sukhdev and Kumar, 2010; van der Ploeg et al., 2010; de Groot et al., 2012). Like all estimates at this scale, this is obviously a major simplification. However, for the purposes of this exercise, it was thought to be sufficient as an initial estimate. Obviously, much more elaborate and sophisticated modelling and analysis can be done (Boumans et al., 2002, 2015; Turner et al., 2016), but this is left for future studies.

The unit value changes were based on policy and management assumptions likely to occur in each scenario.[7] These unit value changes also reflect the changed preferences of the populations living within those scenarios. For example, in the Policy Reform (PR) scenario, it was assumed that a slight improvement in policies around the environment and ecosystem services would allow maintenance of the 2011 unit values until 2050, while in Fortress World (FW), unit values would decrease by 20 per cent on average. It also assumes that the populations in Fortress World will value ecosystem services to a lesser degree then the population in Great Transition. These percent changes were based roughly on the estimates included in the Bateman et al. (2013) study of six future scenarios for the UK. However, they are not intended to be empirically derived, but rather are plausible estimates of the relative magnitude of change that *could* occur under each hypothetical scenario. In general, the following was assumed for each of the four scenarios:

1. **Market Forces-Free Enterprise:** decrease in consideration of the environmental and non-market factors resulting in an average *10 per cent reduction in unit values* from their 2011 levels. In this scenario, climate change has not been dealt with.
2. **Fortress World-Strong Individualism:** *Significant* decrease in consideration of environmental and non-market factors resulting in an average *20 per cent reduction in unit values* from their 2011 levels. In this scenario, climate change has accelerated.
3. **Policy Reform-Coordinated Action:** Slight improvement from 2011 policies and management leading to *no significant change in unit values* from their 2011 estimates. In this scenario, climate change has been moderated.

[7] Values within the scenarios are not discounted because values used within the future scenarios are not being converted into present values.

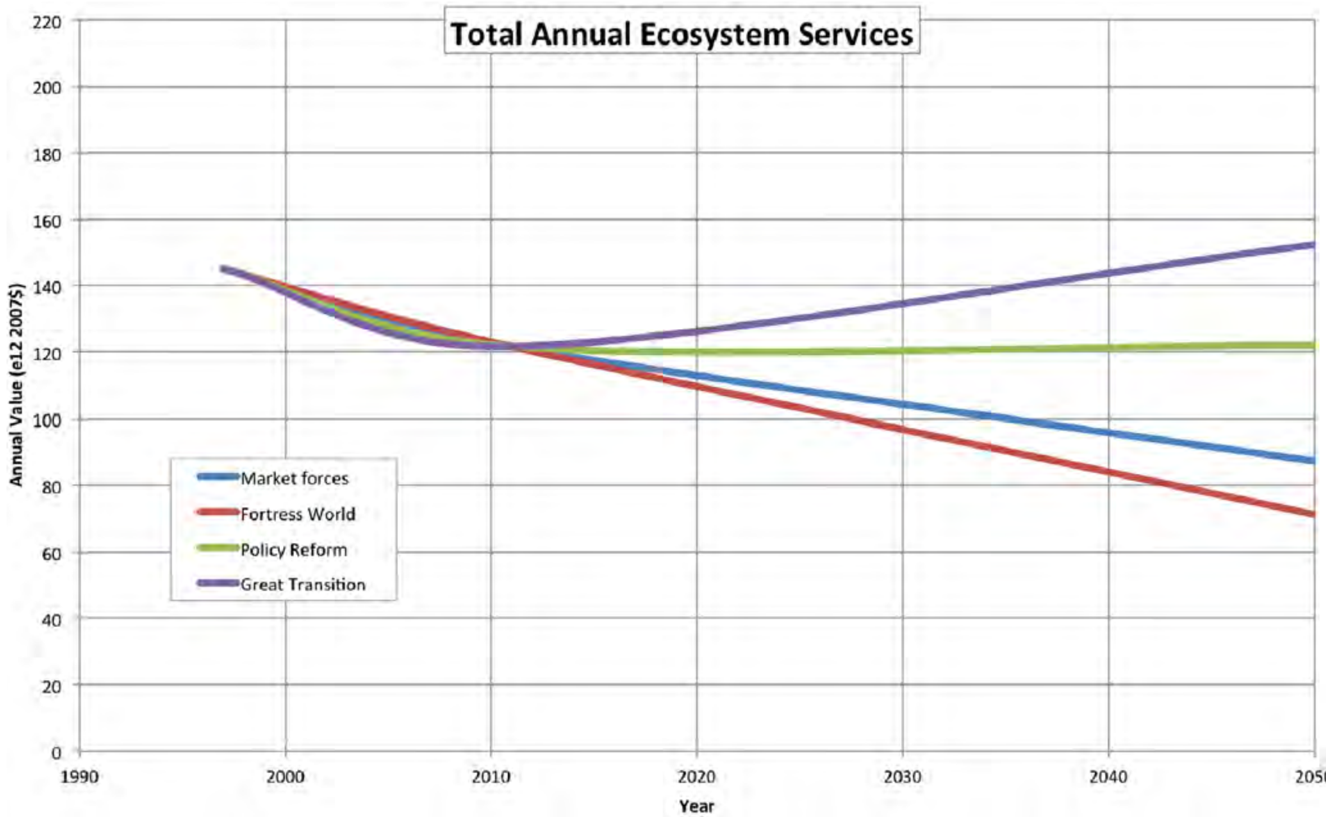

Fig. 3. Global total annual flow of ecosystem service values. This graph shows the total values for each scenario through 2050 when both the unit values and land areas are changed.

4. **Great Transition-Community Wellbeing:** *Significant* increase in consideration of environmental and non-market factors resulting in an average *20 per cent increase in unit values* from their 2011 levels. In this scenario, climate change has been addressed.

As part of our sensitivity analysis, we present results both with and without these changes in unit values (Tables 2 & 3). A related issue has to do with how changes in the relative scarcity of ecosystems, reflected in changes in relative land area, affects unit values. For marketed goods decreasing supply, all else being equal, usually implies increasing price. However, most of the ecosystem services included are non-rival, non-excludable, and non-marketed public or common property goods and services. This implies that their unit values may not be as greatly affected by relative scarcity from reduced area as much as by population demand. However, these supply and demand relationships are difficult to estimate even in the best of cases and for the purposes of this study, we assumed that changes in supply are the major factor and the unit values will change mainly as a function of management policies and ecosystem health and condition that these imply, as described above. We leave it for future integrated modelling work to take this research to the next level.

5. Mapping

The aggregate areas of each biome in 2050 were derived from the GTI scenarios and are shown in Table 1. We recognize that there is considerable uncertainty in global land use projections (Alexander et al., 2017). These projections lie well within the range of possibility and are consistent with the other assumptions built into the GTI scenarios.

We next developed an algorithm to estimate how these changes in aggregate land cover would be distributed across the landscape to create global land cover data layers, at 1 km^2 resolution, for 2011 and the four scenarios. Our algorithm distributed the percentage changes in land cover from the aggregate scenario projections in the most likely locations (see Supplementary information for a more detailed description). A modified version of the GlobCov data product[8] was used as the original base data for 2011. For each scenario, each 2011 land cover extent grew or shrank based on the percentage changes of that land-cover in that scenario's aggregate projection. All growth and loss was adjacent to the existing 2011 extent of that land cover. Our algorithm needed to establish precedence for these land cover transitions. This was assumed to occur in the following order: urban, wetland, cropland, forest, rangeland/grassland, and desert. This precedence worked in such a way that all previous land cover transitions are excluded from further conversion (e.g. cropland cannot replace urban or wetlands). Two other terrestrial land covers (ice/rock and lakes/rivers) were held constant across all four scenarios. Tundra was not a land cover category in the GTI scenarios and we also lacked estimates of its ecosystem service value. For these reasons we used tundra as a slack variable to absorb gains or losses of spatial extents of the other biomes. Most losses occurred within the six included land-covers, at lower latitudes. However, in two scenarios (PR and GT), tundra area changes slightly (by less than two percent). Although, the assumptions made by this model are significant, the order of precedence for these land cover transitions was chosen based on most likely conversion order. However, this order did not affect our major conclusions.

The results of the global land use change algorithm can be presented as tables and maps at 1 km^2 resolution (Fig. 2). However, it

[8] http://due.esrin.esa.int/page_globcover.php

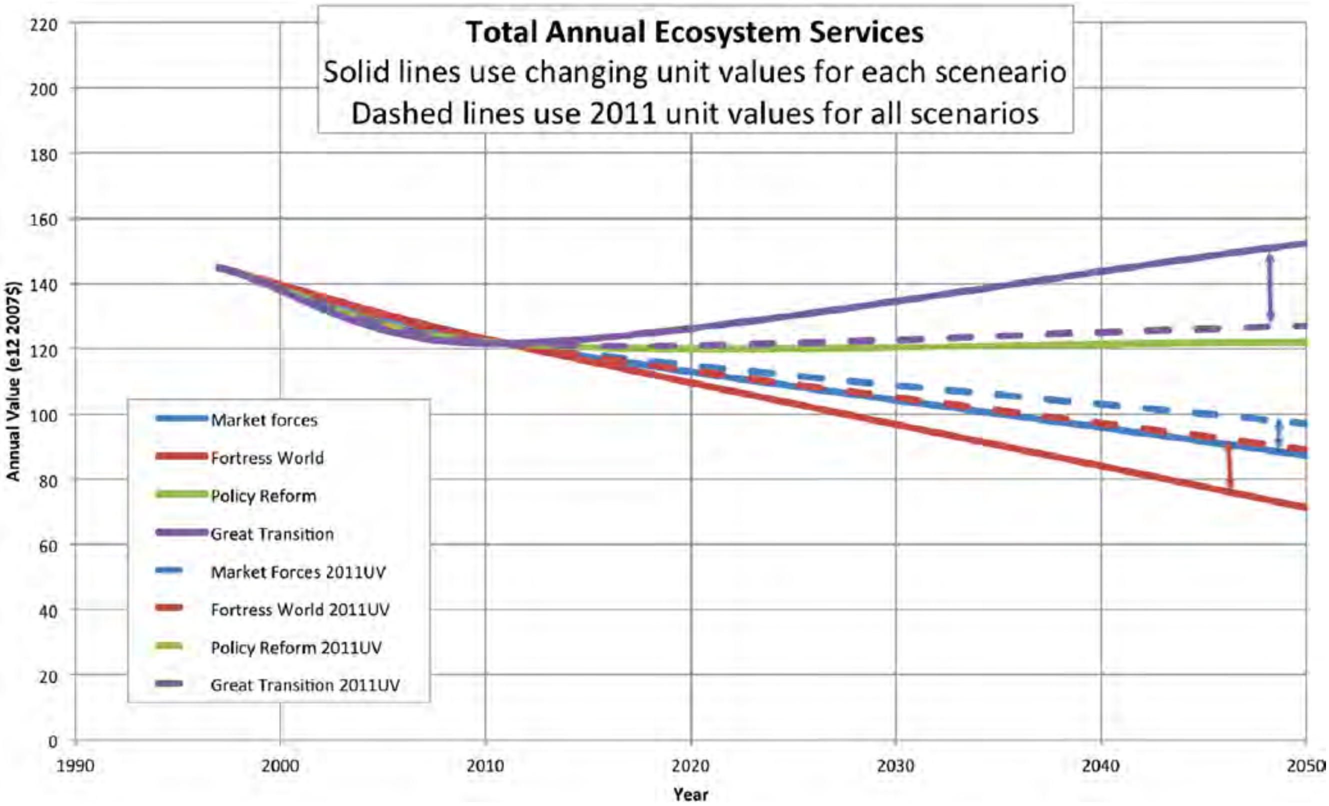

Fig. 4. Comparison of ecosystem service values. This graph shows the difference between the total annual ecosystem services value when the values are left at those used in 2011 and when the unit values are changed for each biome (based on the different priorities embodied in each of the scenarios). This shows the impact of just changing the land-use areas.

is difficult to see changes in the spatial patterns within country boundaries at a global resolution, or how these changes impact countries and regions. Therefore, to better show these effects, we extract results for any country or region in the world. This paper presents global maps (Fig. 2) and tables (Tables 1–3), a table with all country values (Table S1), and maps and tables for a few countries as examples to represent each continent: Australia (Fig. S1a), Brazil (Fig. S1b), China (Fig. S1c), Germany (Fig. S1d), India (Fig. S1e), South Africa (Fig. S1f), and the United States (Fig. S1g).

6. Limitations and caveats

This paper analyses the implications for the value of ecosystem services of potential changes in global land use and management out to the year 2050 for four archetypical scenarios developed by the GTI. It uses several simplifying assumptions to arrive at these estimates, including:

1. The scenarios are simplifications of complex futures. They are not intended to be predictions of the future, but rather to lay out a set of plausible futures that cover the range of possibilities. This is a limitation of any scenario analysis, but it is worth noting here again, since there is a tendency to interpret the results as predictions.
2. The per unit area values for ecosystem services by biome are assumed to be constant over space. Matching heterogeneous demand and supply across space is therefore not modelled and this is an issue for all services except carbon sequestration.
3. Changes in ecosystem services value are assumed to be due to changes in land use and management. Changes due to relative scarcity, demand, or quality are not modelled. Climate change and other large scale changes that affect per unit values are assumed to change in a way unique to each scenario and the effects of these changes on ecosystem services values are simplified to overall changes in land use and unit values.

These simplifying assumptions obviously limit the accuracy of the results, but do not, we believe, change the general conclusions. Remember, again, these are scenarios, not predictions.

7. Results and discussion

7.1. Global scenarios

Table 2 shows the global land area, unit values, and the total annual flow value for each of the biomes. It also shows the total global annual ecosystem service flow value for each scenario. The black numbers show values that have remained the same in each scenario as compared to the 2011 values, numbers in red show a decrease, and green numbers show an increase. Using the land-use changes for each biome shown in Table 1 (Raskin et al., 2002), the land area of forests (both tropical and temperate/boreal) and grass/rangelands decreased significantly in all scenarios except GT, as compared to 2011 areas. Wetlands (both tidal marshes/mangroves and swamps/ floodplains) and ice/rock area decreased in the MF and FW scenario, while they increased or remained the same in PR and GT. Desert area increased in all the scenarios except GT and tundra area decreased in all scenarios. Unit area of cropland and urban both increased in all four scenarios. On the marine side, the area of algae beds/seagrass increased in MF and FW, remained the same in PR, and decreased in GT. Coral reef extent decreased in MF and FW, remained the same in PR, and increased in GT. Even though marine systems are not 'land', their functioning is highly

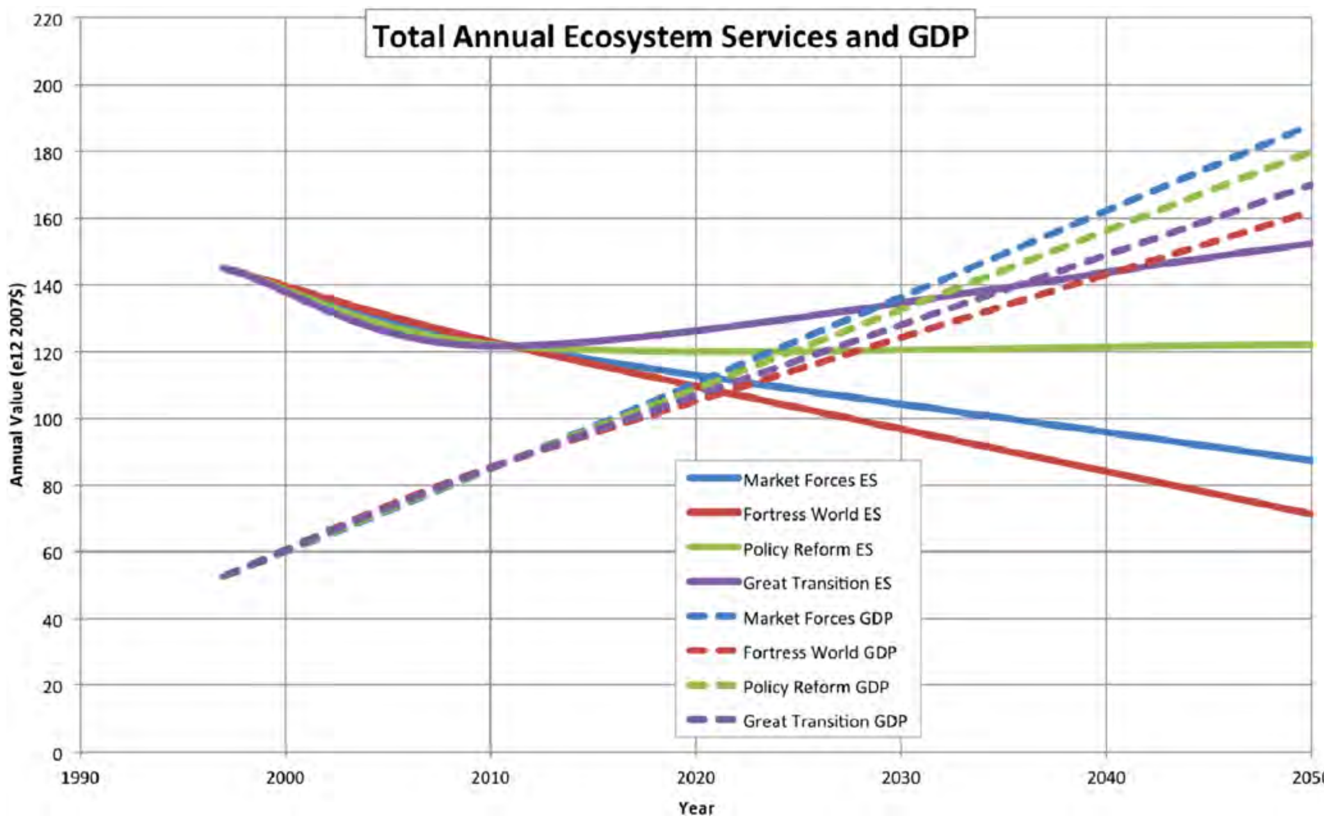

Fig. 5. The four solid lines show the annual value of ecosystem services for each of the four scenarios going out to 2050. The dashed lines show GDP for each of the four scenarios going out to 2050. The ecosystem services values and the GDP for the four scenarios were not added or combined in this figure.

influenced by climate and land-based activity, especially coastal systems like coral reefs.

The unit values per biome were adjusted from 2011 values as described above. However, in order to show the sensitivity of the results to the changes in the 2011 unit values, Fig. 4 and Table 2 provide results without changes to the unit values. The general trends and conclusions are unchanged, only the magnitudes are different.

Putting the land areas and unit values together for each biome, the global total annual flow of ecosystem services values was estimated (Fig. 3)[9]. The total global values in both MF and FW were all lower than in 2011, dropping to USD $87.3 and $71.3 trillion/yr, respectively, from a 2011 value of USD $121.6 trillion/yr. The values in PR increased a small amount to USD $122.0 trillion/yr, mostly due to the fact that marine unit values did not change, forest and grassland/rangelands unit values decreased, and wetlands, croplands, and urban unit values increased. In the GT scenario, on the other hand, total global value increased to USD $152.3 trillion/yr (Table 2).

We note here the sensitivity of the results to assumptions about wetland land use changes. This category of land use was not included in the GTI scenarios, but we know, based on their unit values, that wetlands are among the most valuable ecosystems on a per ha basis. The changes in wetland area are thus responsible for a major fraction of the changes in ecosystem services value between scenarios, even though they represent a small fraction of total global land use. It is clear that changing the assumptions about wetland land use changes would affect these results, but we feel that the direction of change and general conclusions would not change.

[9] We explicitly only present annual values over time and avoid Net Present Value estimates and the discounting of future values that would entail.

Fig. 4 shows the total global annual ecosystem services values when the unit values are unchanged from those used in 2011 and only area extents are changed for each biome. MF and FW decreased to USD $97.0 (11% more than with unit value changes) and $89.1 (25% more than with unit value changes) trillion/yr from 2011 total values, respectively, when only the area was changed, keeping the unit values constant. Total PR values remained the same at USD $122 trillion/yr while GT total values increased to USD $127.0 trillion/yr (17% less than with unit value changes) when unit values were kept at 2011 levels (Table 3). This comparison shows that using 2011 unit values creates a pattern similar to that when the unit values are changed for each scenario. The only difference is that the change to the total values for each scenario is reduced. This occurs because the changes in unit values amplify the existing changes in area cover of the biomes. Changes in biome areas produce significant changes in global ecosystem service values, regardless of unit values.

The gross domestic product (GDP) for each scenario (obtained from the GTI scenarios) is shown in Fig. 5. MF has the highest GDP since economic growth is the end goal of the society in that scenario. PR follows closely behind as it fosters economic growth while simultaneously passing policies to preserve ecosystems and the services they provide. GT comes third because even without the focus on economic growth, the society and economy are healthy and prospering. FW's is lowest since global society is deteriorating, with social, environmental, and economic problems reaching a point of collapse.

7.2. National implications

Using the global 1 km^2 land use projections created for the four scenarios, the change in estimated Total Ecosystem Service Value

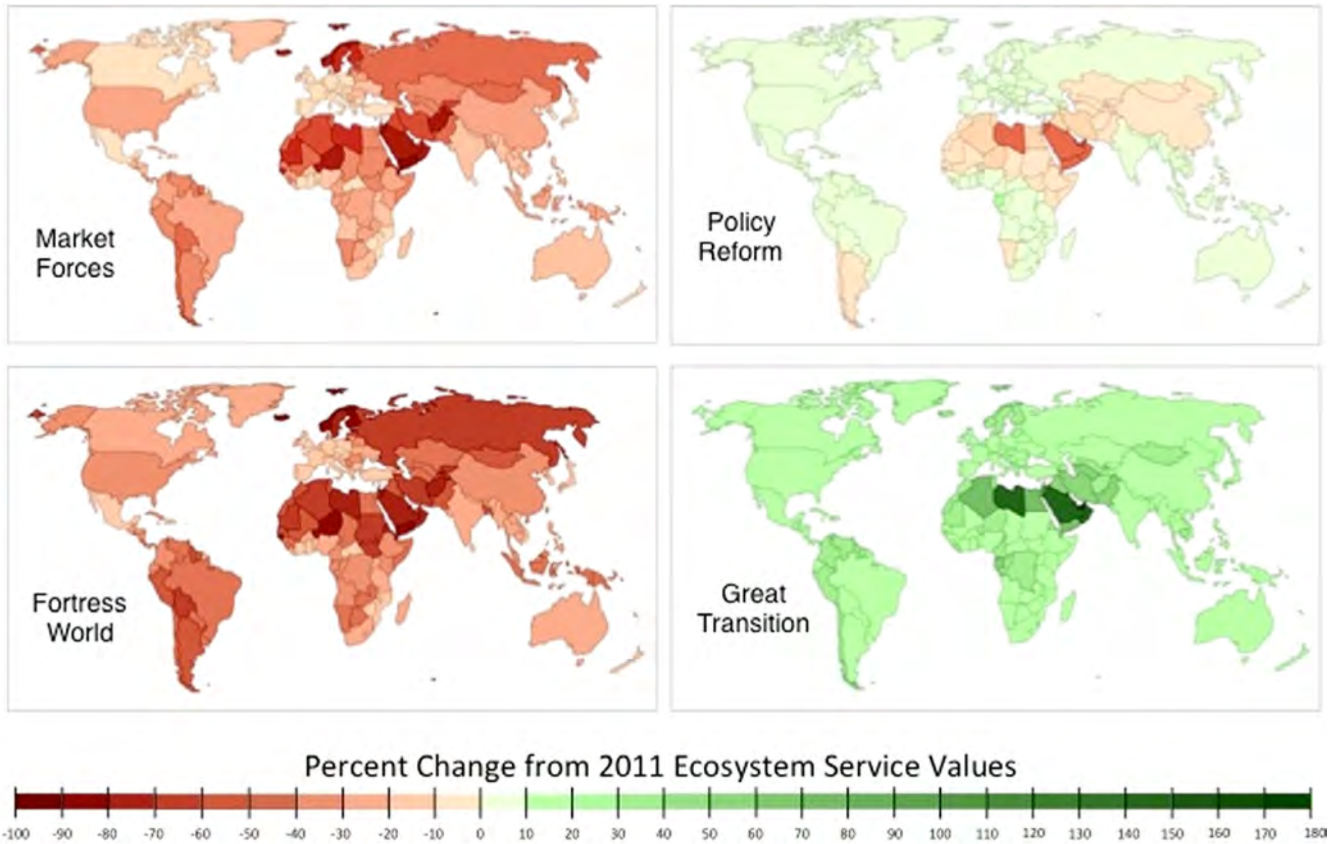

Fig. 6. Global map showing the scale of percent change for each country in ecosystem services value in each of the four scenarios from the 2011 base map.

(TESV) for any country or region in the world can be extracted. Supplementary Table S1 shows the 2011 TESV and the TESV for each of the four scenarios, for each country in the world. These are terrestrial and coastal values only, as it was difficult to assign marine values to particular countries. It also shows the percent change in the TESV from the 2011 values for each of the countries. Fig. 6 shows this percent change for each country using a colour spectrum. Darker red shows a greater loss of TESV in each country, while a darker green shows a greater gain. This difference between countries occurs due to varying areas of different biomes. For example, countries with more deserts will experience a greater desertification rate then those countries without existing desert.

When looking at the percent change from 2011 TESV for each country in the Market Forces (MF) scenario, we find that Djibouti (−82%), Yemen (−81%), and Jordan (−78%) show the greatest losses in ecosystem services. These countries show the greatest losses due to their propensity for desertification. Luxemburg was the only country that showed a minor increase in ecosystem services value in the MF scenario of 2%, likely due to its small size and primarily urban land cover. All other countries experience a loss, Slovenia (−1%) and Czech Republic (−1%) showing the least loss after Luxemburg. However, the change in ecosystem service value is so small, it is negligible.

In the Fortress World (FW) scenario, the countries that experience the greatest loss in ecosystem services value were Guinea-Bissau (−88%), Norway (−87%), and Iceland (−86%). Guinea-Bissau's loss is due to increased desertification while the losses in Norway and Iceland are due to loss of rangelands and forests. No countries experienced an increase in ecosystem services value; the ones that had the lowest percentage of loss were Luxemburg (−4%), Czech Republic (−9%), and Saint Helena (−9%). These are all small countries with a significant portion of their land area covered by urban.

In the Policy Reform (PR) scenario, some countries experience a loss in ecosystem services while other experience a gain. However, none experience massive change in either direction like in the other scenarios. The countries in the Middle East experience the majority of the lost, most notably Qatar (−49%), United Arab Emirates (−44%), and Oman (−40%) due to desertification. The ones that experience the most gain include Equatorial Guinea (12%), Gabon (10%), and Luxemburg (9%).

In the Great Transition (GT) scenario, only one country experiences a loss in ecosystem services and that is British Virgin Islands with a −7% loss. The countries that experience the least gain are Mayotte (7%) and American Samoa (10%). However, the countries that experience the most gain in ecosystem services are those that experience the most lost in others. These include United Arab Emirates (173%), Qatar (164%), and Oman (133%). This is due to the fact that GT is the only scenario in which deserts decrease. Although not by a great amount globally, the decrease in deserts makes a significant difference in these countries that have a significant proportion of deserts.

Using the global land use change model created for the four scenarios, we can also extract the land area changes and impacts on ecosystem services values in detail for any country or region. In this paper, we pulled out Australia, Brazil, China, Germany, India, South Africa, and the United States from the global model as examples. The results for these seven countries can be seen in Fig. S1(a–g), which includes maps of land cover for each biome for the base map and the four scenarios, changes in the land cover between 2011 and each of the four scenarios (shown as those pixels that changed or did not change), and the change in ecosystem

Table 4
The terrestrial values for ecosystem service in 7 countries and globally for the 2011 base and each of the four future scenarios.

Country	Area (thousand km^2)	ESV_2011 (Billion $/yr)	S1_MF (Billion $/yr)	MF% change from 2011	S2_FW (Billion $/yr)	FW% change from 2011	S3_PR (Billion $/yr)	PR% change from 2011	S4_GT (Billion $/yr)	GT% change from 2011
Australia	7,719	$ 3,372	$ 2,730	−19%	$ 2,391	−29%	$ 3,360	0%	$ 4,089	21%
Brazil	8,524	$ 6,768	$ 4,727	−30%	$ 3,717	−45%	$ 6,868	1%	$ 8,461	25%
China	9,425	$ 3,587	$ 2,596	−28%	$ 2,314	−35%	$ 3,495	−3%	$ 4,525	26%
Germany	357	$ 197	$ 181	−8%	$ 163	−17%	$ 207	5%	$ 242	23%
India	3,167	$ 1,825	$ 1,563	−14%	$ 1,358	−26%	$ 1,834	0%	$ 2,204	21%
South Africa	1,171	$ 476	$ 399	−16%	$ 351	−26%	$ 478	0%	$ 572	20%
USA	9,470	$ 5,331	$ 4,123	−23%	$ 3,279	−38%	$ 5,395	1%	$ 6,469	21%
Global terrestrial	1,48,22,000	$ 71,971	$ 49,309	−31%	$ 38,790	−46%	$ 72,348	1%	$ 90,044	25%

services value from the 2011 values to each of the four scenarios within that country or region.

Table 4 shows the total ecosystem services values per year for the 2011 base map and each of the seven countries, for each scenario. In MF and FW scenarios, all the countries experience a loss in ecosystem services. Brazil experiences most loss (−45%) in the FW scenario due to loss of tropical forests. This is still lower than the global average of −46%. In the PR scenario, none of the seven countries experience major losses or gains in ecosystem services. The only one that experienced a loss was China (−3%) while Australia, India, and South African saw no net change. Brazil and the US experience a positive change of 1% and Germany is the only one above the global average with an increase of 5%. In the GT scenario, the increase in ecosystem services in all the countries is in the 20% range, a bit lower than the global average, which was around 35%. However the country maps and totals do not include marine systems, which are picked up at the global scale.

As a check on the effects of unit value specificity and spatial resolution and on the results, a comparison was done between the ecosystem service values for individual nations determined by this global model and more localized national studies. A 2013 national study found that the total ecosystem service value for the Kingdom of Bhutan was USD $15.5 billion/yr (Kubiszewski et al., 2013). The current global study determined that the total ecosystem services value of the same area was USD $14.9 billion/yr (Supplementary Table S1), only a 4% difference. A similar comparison was done for the country of South Africa. The current global study found that the total ecosystem service value in 2011 for South Africa was USD $476 billion/yr (Table 4). While a more detailed study found a total ecosystem service value for the same area of USD $515 billion/yr, a difference of just under 8% (Anderson et al., 2017). The relatively small differences found between the national studies and this global study suggests that the coarser spatial land use resolution of the global analysis and the use of global average unit values does not introduce significant differences in the total values, compared with higher spatial resolution national studies using more site specific unit values.

8. Conclusions

The large differences in the estimated total annual ecosystem services values between each of the four scenarios shows the kind of impact that land-use and management decisions can have going forward. A difference of USD 81 trillion/yr globally in the value of ecosystem services between the FW and GT scenarios can mean life or death for many people, especially those in developing countries (Adams et al., 2004). The GT scenario is an ecosystem services restoration scenario. It can reverse the current trends in land degradation and allow for a sustainable and desirable future, in a world that also addresses climate change while enhancing other critical services, especially those that are important to the poor.

We emphasize again that these results are *estimates* and *scenarios*, not measurements and predictions. We cannot *predict* the future, but we can *create* it based on the choices we make in the present. Our estimates are intended to help inform those choices by making the connection clearer between future human wellbeing and the wellbeing of the rest of nature in quantitative terms that highlight the decisions and trade-offs we have to make now.

The GT scenario (and to a lesser extent the PR scenario) can also be seen as embodying many of the goals recently agreed to by all countries in the UN Sustainable Development Goals (SDG) process (United Nations, 2015). The GT scenario (and to a lesser extent the PR scenario) assumes reduced inequality, reduced hunger, better management of land and sea ecosystems, arresting climate change, sustainable production and consumption, and many other features also listed among the 17 SDGs. Achieving the SDG's will thus provide a significant enhancement of ecosystem services and this paper has provided one early estimate of the magnitude of that potential enhancement.

Our scenarios can help decision makers deal with uncertainty and design policies to improve the chances of better futures actually occurring. They can also be used to engage the larger public in thinking about the kind of future they really want. Scenarios can be used as the basis for public opinion surveys to gauge preferences for different futures at the global and national scales (Costanza et al., 2015). Our results provide estimates of the changes in ecosystem services that can be incorporated in these surveys.

Our approach in this study is admittedly simple and straightforward. We do not imply that the unit values or the scenarios we use are precise estimates of the present or predictions of the future. We merely attempt to provide a spectrum of possibilities, which is all that a scenario analysis can realistically hope to do. However, the simplifying assumptions we make (extrapolation from a limited number of site-specific estimates, constant unit values per hectare per biome, not considering dynamic interdependencies, etc.) most likely lead to underestimates of the true value of ecosystem services (Boumans et al., 2002; Costanza et al., 2014), so we consider our estimates to be conservative.

Future work can improve and extend these initial estimates. For example, recent approaches to the uncertainty and transferability of monetary valuations can be used to better describe uncertainty and improve benefit transfer based mapping (Schmidt et al., 2016). Using global and landscape scale computer simulation models can help create and evaluate integrated scenarios for ecosystem restoration for comparison with business as usual (Boumans et al., 2002; Turner et al., 2016). These approaches hold significant promise for reversing land degradation by using comprehensive ecological-economic frameworks, assessments, models and arguments as an aid for better decision-making.

To get there, these approaches need better integration into national income and wealth accounts, assessments of environmental costs and benefits in project appraisal, full cost accounting of business activities, and a range of other uses. There is significant progress in this direction with the advent of the IPBES, the Ecosystem Services Partnership, TruCost LLC, and many other global and regional initiatives. The SDGs recognize that the world we all want is similar to the GT scenario. The missing facet of the SDGs is an overarching goal with clear metrics of progress toward that goal. Another critical missing aspect is a dynamic model showing how the 17 SDGs interact and trade-off with each other (Costanza et al., 2016). Assessing the value of ecosystem services is central to this task and allows us to build comprehensive, integrated measures of sustainable wellbeing that can drive progress toward that goal.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoser.2017.05.004.

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