Modeling climate change and biodiversity effects on the value of ecosystem goods and services: an empirical investigation on the European forest ecosystem

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Abstract

The paper conducts an empirical investigation on the relationship between biodiversity and the values of ecosystem goods and services that are supported by biodiversity and ecosystem functioning and tries to quantify the magnitudes of this complex relationship. Climate change, here interpreted as increase in temperature, is one of the major drivers today that alter the pattern of biodiversity distribution, affect the ecosystem functioning and change the flows of ecosystem goods and services to be provided by a healthy ecosystem. Therefore, it is an essentially first step to determine the most suitable biodiversity indicator that is both sensitive to climate change impact and useful to explain its interaction with ecosystem services. Furthermore, a two-step model is developed to capture the marginal impacts of changes in biodiversity on the value of ecosystem goods and services due to climate change. Our results show that increase of 1°C in the local temperature can contribute proportionally to the decrease of marginal value of ecosystem services, but the magnitudes of the impacts vary dramatically depending on the choice of biodiversity indicators, the types of ecosystem services, the geo-climatic region in which the ecosystem is located, and the specific IPCC scenarios under consideration.

Keywords: Biodiversity, Composite biodiversity indicator, Forest ecosystem services, Climate change impact

JEL: Q23, Q51, Q57

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1. Introduction

It has been widely recognized that the conservation of biodiversity and natural ecosystems is essential not only for their role in the stabilization of ecosystem functioning (e.g. global carbon cycle) but also for their socio-economic significance through the provision of a wide range of ecosystem services critical to human well-being including human health, livelihoods, nutritious food, security and social cohesion (Secretariat of the CBD, 2009; MEA, 2005). The relationship between biodiversity and ecosystem functioning or primary productivity has been of long-standing interest to ecologists (Kinzig et al., 2001; Loreau et al., 2001, 2002; Cameron, 2002). With the advances in science and technology, it has been shown that biodiversity influence the rate or nature of ecosystem processes. Despite of the difficulty in finding a general ecological relationship between ecosystem function and diversity because of species-specific effects and important tropic links (Paine, 2002; Willims *et al.,* 2002), a majority of studies have found that biodiversity loss has a negative effect on ecosystem function (Giller and O'Donovan, 2002; Schmid *et al.,* 2000; Bloger, 2001; Loreau *et al.,* 2001). Whereas the socio-economic dimensions of biodiversity and ecosystem have made the subject also an emerged central issue in the areas of environmental economics and public policies during the last decade (Cameron, 2002), and resulted in many attempts both to conceptualize and value biodiversity in economic terms (Kontoleon *et al.,* 2007). The main assumption behind the economic investigation is that if biodiversity has an influence on ecosystem functioning, then any changes of biodiversity (e.g. biodiversity losses caused by climate change) will affect ecosystem goods and services and human welfare. For the same line of reasoning, if we are able to quantify the biophysical changes of biodiversity, then these changes can also be translated into monetary gains/losses in the welfare economy. This information is of particular importance for enhancing the public understanding of the value of biodiversity and assisting policy makers to reallocate resources among biodiversity and ecosystem conservation strategies in a cost-effective manner.

The mainstream literature of biodiversity valuation has been concentrated on valuing the changes of a certain type of biological species either for its important ecological existing value (e.g. the rare and extinction biological species for research or educational use) that cannot be traded in the market or for its high commercial value (e.g. the pharmaceutical and timber products). A variety of economic instruments[1] have been developed and exercised in different policy contexts to capture both market and non-market values of biodiversity. These methods and the respective valuation results are essential for guiding policymaking process in terms of setting-up conservation priorities and allocating the limited resources for conservation. However, both these techniques and the resultant biodiversity values are highly debatable for many reasons. First, no one method is capable of valuing all aspects of the total economic value associated with biodiversity change and alternative integrated valuation techniques are therefore preferred (Christie *et al*, 2004; Nijkamp *et al*, 2008). Second, other criticisms around the nature of biodiversity valuation are raised by ecological economists, who argue that the revealed value of biodiversity derived from people's willingness to pay reflects human desires and preferences but ignores the scare nature of biodiversity *per se* and thus excludes the intrinsic value of biodiversity (Baumgärtner et al. 2006). Finally, the existing valuation methods also failed to capture the marginal effects of biodiversity loss on the values of ecosystem goods and services and shed light on the magnitude of biodiversity impact on human welfare across temporal and geographical scales.

Therefore, it is unquestionable that quantification of the economic value of biodiversity requires the joint use of both market and non-market valuation methods. In fact, in a recent study, Ding et al. (2009) tried to use a hybrid ecosystem-based valuation approach, which combines the use of existing valuation methods to estimate the welfare losses in Europe due to the reduction of various forest ecosystem services in different climate change scenarios. Moreover, as traditional focus of nature conservation has switched from biodiversity to the goods and services from ecological system that benefit people, more efforts should be put on the investigation of the impacts of biodiversity loss on the ecosystem goods and services to be delivered to human being, as well as on the quantification of these impacts in economic terms. However, studies that aim at quantifying the relationship between biodiversity - ecosystem services and their contributions to human welfare remain crude in the literature, except two interesting studies recently conducted by Costanza et al. (2007), who empirically explored the relationship between species richness and net primary production for the U.S. and by Ojea et al. (2009), who extended the investigation to a global scale by exercising a meta-analysis on the worldwide forest ecosystems and a range of ecosystem services. Thus, the present paper is

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[1] Commonly used valuation methods include: replacement/restoration/reallocation costs, preventative expenditure, averting behavior, Travel Cost Method (TCM), Hedonic Pricing (HP), Contingent Valuation Method (CVM) and Choice Experiments (CE).

aimed to contribute to this line of research by undertaking an empirical analysis on the marginal effects of biodiversity changes on the value of ecosystem goods and services in the context of climate change. More specifically, our study will particularly address two central questions, i.e. what are the most relevant biodiversity indicators to be used to measure the impacts of biodiversity change on ecosystem services' values and how to quantify the magnitude of these marginal effects in monetary terms. The paper will focus on European forest biodiversity and explore its welfare effects in EU-17 as a result of climate change.

The organization of the article is as follows. Section 2 introduces the four climate change scenarios for investigation in the paper. Section 3 provides a review of the literature on biodiversity indicators and develops two new composite indicators to be included in the empirical model. Section 4 describes the economic database included in the present empirical analysis. Section 5 develops a two-step model for the empirical analysis and presents some preliminary results. Section 6 concludes with a summary of the main findings.

2. Climate Change Impact and the IPCC Scenarios

To investigate the potential economic effects of climate change and different policy scenarios on EU forest ecosystems as well as the associated ecosystem services' values, we rely on the climate change scenarios developed by Intergovernmental Panel of Climate Change (IPCC) (we call them IPCC scenarios throughout the paper). Four descriptive scenario families of the Fourth Assessment Report, i.e. A1, A2, B1 and B2 scenarios are assessed[2], subject to different assumptions on carbon dioxide emissions, global average surface temperature increase and patterns of economic development (see ***Table 1***). Scenario A1 and A2 are the more economic oriented scenarios. In Scenario A1 different combinations of fuel are also considered (scenario A1F1). Scenario A2 represents a world differentiated into a series of consolidated economic regions characterized by low economic, social, and cultural interactions, uneven economic growth and with the income gap between industrialized and developing countries that does not narrow. In scenario B1, environmental and social consciousness is combined in a more sustainable development. Although no specific climate policy is included, the technological shift

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[2] Scenarios from the A1 family could not be evaluated for lack of data on the trends of GDP per capita and total population in the IIASA GGI Scenario Database.

towards renewable energy plays an important role. A more equitable income distribution than in scenario A2 is achieved. Similarly to scenario B1, scenario B2 is environmentally oriented with a focus on both environmental and social sustainability, but locally oriented. Government policies and business strategies show a trend toward local self-reliance and stronger communities while international institutions decline in importance. Technological development plays a smaller role than in scenario B1 and innovations are also regionally more heterogeneous.

Table 1. The specifications of the four IPCC scenario families

Scenarios by 2050	Climatic model (HadCM3)			
	A1FI	A2	B1	B2
Storyline	Global economic	Local economic	Global environmental	Local environmental
CO2 concentration (ppm)	779	709	518	567
Δ Temperature (°C)	4.4	2.8	3.1	2.1
Socio-economic dimensions	High savings, high rate of investments & innovation	Uneven economic growth, high per capita income	High investment in resource efficiency	Human welfare, equality, environmental protection

Source: adapted from: IPCC 2001; Schroeter et al. 2005

These IPCC scenarios developed by world-class academy in field of climate study over the past decades are the basis for projecting trends of climate change and possible consequences of the impacts in both natural and socio-economic systems. In fact, large database are readily available to show the trends of future GDP, population, incremental temperature, ecosystem productivity, distribution of species and so on, following different future paths described by the four IPCC storylines. For this reason, the present paper adopts the IPCC definitions as well as the best available database derived from different sources of IPCC data distribution center. For example, data on the trends of GDP density (ratio of GDP and land area of a country) and population by 2050 in the four IPCC scenarios are derived from the work of the Center for International Earth Science Information Network (CIESIN, 2002), one of the main IPCC data distribution centers – See ***Table 2***.

Table 2. Trends of GDP and Population in IPCC scenarios (2050)

Country	Population density (head/ha)[a]				GDP per capita (000'US$)			
	A1	A2	B1	B2	A1	A2	B1	B2
Greece	0.41	0.41	0.41	0.37	27.38	21.36	21.87	19.30
Italy	1.06	1.06	1.06	0.92	73.52	57.36	58.73	53.65
Portugal	0.63	0.63	0.63	0.56	23.17	18.08	18.51	16.70
Spain	0.57	0.57	0.57	0.51	47.14	36.78	37.66	33.13
Austria	0.87	0.87	0.87	0.89	72.06	56.21	57.56	44.74
Belgium	3.33	3.33	3.33	3.05	59.96	46.78	47.90	41.50
France	1.10	1.10	1.10	0.93	57.47	44.83	45.91	42.67
Germany	2.12	2.12	2.12	1.85	70.11	54.70	56.01	50.67
Ireland	0.53	0.53	0.53	0.35	26.44	20.63	21.12	25.44
Luxembourg	2.99	2.99	2.99	1.78	45.75	35.69	36.55	48.56
Netherlands	3.169	3.19	3.19	2.73	54.83	42.77	43.80	40.53
Switzerland	0.93	0.93	0.93	1.02	117.04	91.30	93.49	67.46
United Kingdom	1.66	1.66	1.66	1.49	49.00	38.23	39.14	34.44
Denmark	0.14	0.14	0.14	0.13	77.26	60.27	61.71	52.19
Finland	0.12	0.12	0.12	0.12	85.15	66.43	68.02	54.17
Norway	0.10	0.10	0.10	0.09	69.32	54.08	55.37	50.38
Sweden	2.11	2.11	2.11	2.32	88.51	69.05	70.70	50.90

Notes: [a] Source: CIESIN (2002)

3. The choice of biodiversity measurements – biodiversity indicator

Biological diversity is "the variability among living organisms from all sources" (CBD, 1992), including diversity within species, between species and of ecosystems (Heywood, 1995). The diversity of life is generally defined at three levels: genetic species, ecosystem and functional (Nunes and van den Bergh, 2001) and measured by a multitude of biodiversity indicators that summarize complex data into simple, standardized and communicable figures for different purposes. The currently available biodiversity indicators are used to measure (1) *population and distribution trends of selected species*, e.g. species richness, abundance and distribution of the selected species; (2) *trends in extent of different ecosystems and habitats,* e.g. ecosystem coverage and habitat index; (3) *trends in the status of the threatened species*, e.g. IUCN red list index; (4) *trends in the impacts of a specific pressure*, e.g. impacts of climate change species on biodiversity, number and costs of alien species; (5) *the total areas of natural habitats under protection*, e.g. nationally designated protected areas, sites designated under the EU Habitat and Birds Directives (EASAC, 2005; EEA, 2007). Although it is impossible to derive a simple and practical indicator that would reliably cover all abovementioned aspects simultaneously, a single highly aggregated biodiversity indicator can be easily integrated into any environmental outlook reports to support policy making in different political contexts. For instance, the Natural Capital Index (NCI) is one of such kind of indicator. In short, NCI is the product of changes in the area of ecosystems (*"ecosystem quantity"*) and the changes in abundance of a core set of species (*"ecosystem quality"*) within the remaining ecosystem, where both quality and quantity are expressed relative to an "optimal" or "intact" baseline (ten Brink, 2000). It summarizes the extent to which a landscape has preserved its original (baseline) natural capital and enables the analysis of socio-economic scenarios on their effects on biodiversity. One may argue that the choice of best biodiversity indicator depends on the context and the questions to answer. In this essay, choosing the most appropriate biodiversity indicators therefore becomes an essential first step for measuring the effect of biodiversity changes on the ecosystem services' values that biodiversity support.

The present study considers biodiversity at both species and ecosystem levels. At species level, available biodiversity indicators such as species richness and ecosystem coverage will be used to describe the trends of four major species, i.e. trees, plants, birds and reptiles in 17 European countries following different IPCC scenarios. The richness of each of the four selected species and the coverage of forest ecosystems in four different IPCC scenarios are estimated in the frame of the Advanced Terrestrial Ecosystem Analysis and Modelling project (Schroeter, et al. 2004). Moreover, to specify the impact of climate change on biodiversity may vary across regions depending on the type of forests, the national data are divided into three geo-climatic clusters[3]: Mediterranean Europe, Central North Europe and Scandinavian Europe, which are distinguished in terms of their predominant forest types in the region. Finally, we constructed two composite indicators following the NCI framework to measure the quantitative and qualitative changes of biodiversity in response to climate change impact, namely Composite Forest Biodiversity Indicator (CFBI) and Synthetic Biodiversity Indicator (SBI), respectively – See ***Table 3*** for the computation results.

- ***SBI*** is an aggregated qualitative indicator, measuring the average changes in species richness of the four selected species in the context of climate change. It is the product of the variations of species richness of the four individual species projected in four climate change scenario with respect to the baseline condition in 2000 – see Eq.(1). As a result,

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[3] Mediterranean Europe includes Greece, Italy, Portugal, and Spain; Central North Europe includes Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands, Switzerland and UK; Scandinavian Europe includes Denmark, Finland, Norway and Sweden.

we can get four *SBI* figures for each country (*c*), showing the country's average conditions of biodiversity in four different climate scenarios (*s*) with respect to the baseline.

$$SBI\_c_{aggregation}^{Scenario\_vs\_baseline} = \prod \left(FBI\_c_{tree}^{s}, FBI\_c_{bird}^{s}, FBI\_c_{plant}^{s}, FBI\_c_{herptile}^{s} \right) \qquad \text{Eq.(1)}$$

with s = scenario A1, A2, B1 and B2

The resultant SBI ranges in two intervals: (1) [0, 100%]; and (2) >100%. If the *SBI* falls between [0,100%], it represents a potentially deteriorated ecosystem with degradation of biodiversity in future climate scenarios with respect to the current baseline. If the *SBI* is larger than 100%, it shows that the quality of the ecosystem has been improved, along with an increase in the richness of species living inside.

- ***CFBI*** is an integrated indicator as the NCI, which compasses both projected quantitative and qualitative changes in forest ecosystem and biodiversity under climate change scenarios for the EU-17. The mathematical formula of *CFBI* is extended from *SBI* by multiplying an additional term "ecosystem quantity" measured in terms of the projected changes in forest area under four different climate scenarios with respect to the baseline– see Eq.(2).

$$CFBI\_c_{integration}^{Scenario\_vs\_baseline} = SBI\_c_{aggregation}^{S} \times ForestArea\_c^{S} \qquad \text{Eq.(2)}$$

The calculated *CFBI* also ranges in two intervals same as the *SBI*, but shows more integrated information regarding the trends of biodiversity in the EU-17. For example, if *CFBI* falls between [0, 100%], it illustrates that a country's forest ecosystem has deteriorated under climate change scenarios because of the reduction of forest area as a result of land use competition for economic development, or because of the decreased quality of biodiversity in the country, or because of a combination of the both causes. However, if the *CFBI* is larger than 100%, it shows an improved forest ecosystem. The reason of such improvement is not straightforward. It may not be necessarily caused by the increase in species richness of the selected four species in the next decades, but may be due to the extended ecosystem coverage as a result of some effective policy regimes of the country. However, it should be noted that a *CFBI* figure larger than 100% does not mean the local species are not under threats, rather it indicators an overall improvement of the ecosystems due to compensation between different aspects of biodiversity.

Table 3. The projection of CFBI and SBI under the IPCC scenarios

	the CFBI				the SBI			
Country	A1	A2	B1	B2	A1	A2	B1	B2
Greece	12.2%	20.0%	101.7%	105.6%	87.3%	127.8%	100.6%	124.9%
Italy	43.9%	61.8%	211.8%	266.2%	89.6%	132.1%	113.0%	131.9%
Portugal	7.7%	9.4%	41.8%	40.1%	70.8%	85.8%	76.4%	70.7%
Spain	14.5%	17.4%	78.9%	84.5%	70.8%	87.2%	88.9%	90.0%
Austria	474.7%	675.1%	662.2%	831.2%	134.1%	209.1%	201.6%	206.4%
Belgium	35.8%	69.1%	215.5%	434.0%	92.5%	154.6%	180.1%	170.8%
France	42.9%	102.6%	275.2%	431.1%	48.3%	90.3%	99.1%	109.2%
Germany	62.6%	84.3%	250.2%	339.5%	92.3%	123.1%	144.9%	131.8%
Ireland	27.7%	20.3%	191.5%	206.2%	145.3%	197.5%	231.4%	222.9%
Luxembourg	44.4%	78.5%	337.5%	210.5%	60.9%	118.9%	169.5%	154.3%
Netherlands	4.6%	328.8%	131.1%	301.7%	155.9%	186.6%	190.3%	184.2%
Switzerland	399.7%	613.5%	975.7%	931.5%	57.3%	101.8%	108.8%	102.3%
United Kingdom	33.0%	57.8%	179.4%	407.4%	139.1%	178.7%	196.6%	182.8%
Denmark	61.0%	522.3%	110.1%	1375.1%	130.4%	155.3%	193.7%	173.4%
Finland	113.5%	103.3%	81.7%	85.6%	263.8%	252.3%	281.4%	257.9%
Norway	55.6%	44.0%	19.8%	30.4%	244.9%	220.1%	219.8%	214.4%
Sweden	83.7%	76.5%	160.7%	90.2%	181.0%	180.9%	205.6%	195.0%

Table 3 summarizes the results of computed CFBI and SBI for the EU-17 under four different climate change scenarios. Not surprisingly, the two indicators provide very different information regarding the directions of changes of biodiversity in the future. For instance, in the Scandinavian region, biodiversity qualities appear to increase in all the countries under all IPCC scenarios, but the overall biodiversity conditions suffers from a dramatic fall if counting for the quantitative changes as well, see Norway for instance. Moreover, for the same biodiversity indicator, the projections of biodiversity trends vary greatly among different IPCC scenarios (e.g. UK) and across countries (e.g. Austria and Belgium). In comparison, it seems that CFBI is more sensitive to climate change as the magnitudes of the projected biodiversity condition can move from decrease in one scenario to dramatically increase in another scenario, e.g. Greece, Italy, Belgium France, Germany, Ireland, Luxembourg, Netherlands, UK and Denmark. These significant fluctuation of data is mainly caused by changing in the coverage of forest ecosystem in these countries, and to a certain extent, reflects the countries' domestic forest and biodiversity management strategies under different scenario assumptions.

4. Values of Ecosystem Goods and Services in 2050 under Different IPCC Scenarios

Values of ecosystem goods and services that are provided by EU-17's forests are projections under four different IPCC storylines against a baseline in 2000 (See Ding *et al.* 2009 for details). The valuation exercises were conducted separately for three types of ecosystem services defined in Millennium Ecosystem Assessment, i.e. provisioning, regulating and cultural services (MEA, 2005). More specifically, forest provisioning services contains the benefits derived from production of timber and other wood forest products, regulating services provides non-monetary benefits from CO2 sequestration in the forest, and cultural services provides humans with direct incomes from the related tourism industries and non-monetary benefit from the enjoyment of existing forests. Therefore, different valuation methods were applied depending on the nature of each ecosystem service. The values of ecosystem services are estimated by 2050 following four different IPCC scenarios and then adjusted to 2005 US$. ***Table 4*** - ***Table 6*** summarizes the valuation results for each of the three ecosystem services under consideration.

Table 4.The Total Value of WFPs in EU-17: Projections for 2050

(Million US$ 2005)

Country	2005	A1 2050	A2 2050	B1 2050	B2 2050
Greece	141	101	104	166	158
Italy	3,225	1,465	1,447	1,884	2,082
Portugal	1,859	1,760	1,844	2,279	2,301
Spain	3,337	2,212	2,197	2,870	3,233
Austria	5,990	7,510	7,236	5,186	6,897
Belgium	4,807	4,832	3,343	3,513	4,306
France	7,204	4,909	5,281	5,684	6,211
Germany	16,636	12,741	12,712	12,620	14,906
Ireland	506	299	250	304	384
Luxembourg	216	107	104	137	125
Netherlands	3,693	2,568	9,289	5,134	6,375
Switzerland	2,003	2,120	2,039	2,095	1,847
United Kingdom	2,665	2,997	2,925	2,543	3,361
Denmark	465	439	1,067	410	714
Finland	12,067	15,913	15,333	12,985	14,183
Norway	1,863	2,021	1,625	1,476	1,708
Sweden	13,200	17,606	16,984	17,310	16,052

Note: value estimates are adopted from Ding *et al(2009)*

Table 5. The Total Value of Forest Carbon-Mitigation in EU-17: Projection for 2050

(Million US$ 2005)

Country	2005	A1 2050	A2 2050	B1 2050	B2 2050
Greece	9,052	2,695	2,775	4,424	4,230
Italy	4,768	2,617	2,628	3,236	3,075
Portugal	614	273	264	364	337
Spain	2,911	1,796	1,784	2,269	2,218
Austria	3,372	3,690	3,748	3,985	3,900
Belgium	364	185	203	222	212
France	7,020	6,408	6,750	7,466	7,097
Germany	6,703	3,972	4,144	4,969	4,752
Ireland	198	140	136	169	174
Luxembourg	197	89	87	115	104
Netherlands	184	71	166	114	124
Switzerland	1,035	1,349	1,357	1,502	1,428
United Kingdom	1,232	668	796	913	924
Denmark	186	111	208	135	160
Finland	5,487	2,459	2,429	2,831	2,539
Norway	1,740	693	670	731	724
Sweden	7,816	3,879	4,043	5,746	4,370

Note: value estimates are adopted from Ding *et al(2009)*

Table 6. The Total Cultural Value of Forest in EU-17:

Projections for 2050

(Million US$ 2005)

Countries	2005	A1 2050	A2 2050	B1 2050	B2 2050
Greece	390	239	247	566	490
Italy	1,039	869	863	1,756	1,619
Portugal	394	226	227	489	447
Spain	1,864	1,254	1,251	2,615	2,401
Austria	402	222	206	308	218
Belgium	69	22	22	41	34
France	1,619	632	640	1,191	872
Germany	1,153	421	402	753	558
Ireland	70	19	15	38	26
Luxembourg	9	3	3	6	4
Netherlands	38	6	17	20	16
Switzerland	127	83	76	125	84
United Kingdom	296	84	86	194	156
Denmark	52	17	27	30	38
Finland	2,342	462	459	1,039	833
Norway	977	164	160	323	281
Sweden	2,865	576	566	1,629	1,107

Note: value estimates are adopted from Ding *et al(2009)*

5. The empirical investigation

5.1 The hypotheses

It is assumed that climate change disturbance through biodiversity and ecosystem functioning will have an impact on human welfare, the objective of the present paper is therefore to explicitly address this complex interaction and quantify the marginal impacts of climate change induced biodiversity loss in monetary/welfare terms. Our investigation departs from three main hypotheses: (1) climate change, here interpreted as increase in temperature, will alter the pattern of biodiversity distribution, affect the ecosystem functioning to provide goods and services for human consumption and result in some welfare effects, (2) whereas the impact of climate change on biodiversity is not necessary to be evenly distributed across different geo-climatic regions, therefore the marginal effects of the impact should differ from one region to another depending on the types of forest, and (3) since biodiversity play different roles in delivering various types of ecosystem goods and services, the marginal effects of biodiversity loss on the value of ecosystem goods and services should also differ. These hypotheses all lead to one argument that no single one mathematical format can ever be able to express the complex nature of the relationship between biodiversity, ecosystem and human welfare, nether to quantify it. Instead, we propose to use a two-step model to investigate on the marginal impacts of climate change induced biodiversity loss on the value of ecosystem goods and services. More specifically, the first step model is to investigate the potentials of available biodiversity indicators whose changes can be best explained by increases in temperature. Then the resultant marginal effects of climate change on biodiversity can be incorporated into a second step model, in which the relationship between economic values of ecosystem goods and services and biodiversity loss is investigated and quantified.

5.2 The model specifications

Model-1 increase in temperature and biodiversity effects

As mentioned before, the first step of our investigation is to model the relationship between socio-economic and climatic drivers and the resultant changes of biodiversity status. The model was shown by Eq. (3), where the biodiversity indicator is modeled as a function of all exogenous pressures, such as population growth, increasing income, intensive conversion of land use and increased annual temperature as a consequence of climate change. To test the effect of temperature change in biodiversity in different geo-climatic zones, we proceed by introducing the cross products of the temperature and the geo-climatic clusters in the regression. A squared format of changed temperature is introduced to capture the direction and rate of this marginal effect. The semi-log function implies that increase in one degree of the mean annual temperature in a geo-climatic region will have a proportional impacts on the biodiversity (here interpreted as species richness) located in this region. By controlling for different IPCC scenarios, we can provide some insights on the future biodiversity conditions that depend not only on the increase of temperature but also on different policy implications. The results therefore can shed light on some specific policy recommendations for climate change and biodiversity conservation.

$$\ln(BI_s) = \beta_0 + \beta_1 \cdot \Delta T_s^2 + \beta_2 \cdot \Delta T\_Region_s + \beta_3 \cdot \ln(pd_s) + \beta_4 \cdot \ln(gpc_s) + \beta_5 \cdot \ln(fa_s) + \varepsilon \qquad \text{Eq.(3)}$$

BI_s Biodiversity indicators: (1) indicator at species level, including species richness of trees, plants, birds and heptiles (2) indicator at ecosystem level, including Synthetic Biodiversity Indicator (SBI) and Composite Forest Biodiversity Indicator (CFBI);

ΔT_s^2 Squared changes in mean annual temperature in Celsius *degrees*, which captures the rate of temperature changes in different scenarios;

ΔT_Region_s Projected changes in mean annual temperature across different geo-climatic regions;

pd_s Projected changes in population density;

gpc_s Project changes in GDP per capita, reflecting the income level of a country

fa_s Project changes in the coverage of forest ecosystem – conversion between different land uses

s Represents the IPCC scenarios

The model was estimated for all selected biodiversity indicators using Ordinary Least Square (OLS) regression[4], controlling for four different IPCC scenarios. Wald test was performed to test the linear hypotheses on parameters, and the results (with all $P < 0.0000$) confirm that the

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[4] NB: The complete results of diagnostic tests are available upon request.

model specifications were adequate for the analysis. The residuals are tested to be normally distributed using Kernel density plots. The presence of homoskedasticity in the model is investigated by means of Breusch-Pagan test. For all biodiversity indicators, except species richness of heptiles and plants, we can reject the hypothesis of homoskedasitic distribution of the residual at the 5% significance level. Therefore, we removed heptiles and plants species richness from the current analysis, as they are not effective indicator for measuring biodiversity effects due to climate change.

Coefficients estimated for the model are shown in *Table 7* – ***Table 8***, for four biodiversity indictors, i.e. Synthetic Biodiversity Indicator (SBI), Composite Forest Biodiversity Indicator (CFBI), tree species richness, and birth species richness. In general, the results present very interesting insights on the different performance of biodiversity indicators at different levels of biodiversity concerns, i.e. the SBI and CFBI at ecosystem level and species richness of tree and bird species at species level.

Table 7 Estimated socio-economic and climatic impacts on tree & bird species richness

	LNNTS				LNNBS			
	A1	A2	B1	B2	A1	A2	B1	B2
TSQUARE	0.0170* (0.0069)	0.0114 (0.0112)	0.0319* (0.0145)	-0.0300 (0.0215)	0.0036*** (0.0010)	0.0076*** (0.0021)	-0.0033 (0.0036)	0.0107*** (0.0027)
T_MEDI	-0.3882*** (0.0630)	-0.3002*** (0.0850)	-0.4888*** (0.0787)	-0.3074** (0.1033)	0.0023 (0.0092)	-0.0175 (0.0159)	0.0652*** (0.0168)	0.0336* (0.0143)
T_CENNORTH	-0.3025*** (0.0679)	-0.2149* (0.0911)	-0.3704*** (0.0788)	-0.0839 (0.1089)	-0.0183* (0.0092)	-0.0550** (0.0169)	0.0219 (0.0158)	-0.0267 (0.0143)
T_SCANDI	-0.2384*** (0.0676)	-0.1725 (0.0902)	-0.3183*** (0.0832)	-0.0178 (0.1093)	-0.0209* (0.0092)	-0.0513** (0.0169)	0.0325 (0.0194)	-0.0180 (0.0145)
LNPD	-1.1758*** (0.3144)	-0.4202 (0.2563)	-0.0198 (0.2317)	-1.0650*** (0.2579)	-0.0020 (0.0144)	-0.0566* (0.0241)	-0.0607* (0.0263)	0.0325 (0.0287)
LNGPC	-0.1770 (0.1316)	-0.0527 (0.1135)	0.0953 (0.0961)	0.1434** (0.0528)	-0.0437*** (0.0070)	-0.0720*** (0.0113)	-0.0642*** (0.0144)	-0.0828*** (0.0066)
LNFA	-0.2785*** (0.0645)	-0.0218 (0.0586)	-0.0812 (0.0686)	-0.3052*** (0.0413)	0.0165*** (0.0028)	0.0566*** (0.0112)	0.0437** (0.0146)	0.0911*** (0.0044)
_CONS	1.2008*** (0.1572)	1.0117*** (0.1833)	1.1565*** (0.1149)	0.8122*** (0.1391)	0.0436* (0.0195)	0.1297*** (0.0325)	-0.0022 (0.0172)	-0.0023 (0.0198)
N	102	102	102	102	102	102	102	102
R^2	0.8133	0.6449	0.7839	0.8159	0.9518	0.9069	0.8689	0.9562
F	78.1781	24.5017	51.3232	56.4325	721.3600	74.2258	52.1088	222.6597

Standard errors in parentheses

- p<0.05, ** p<0.01, *** p<0.001

First of all, beginning with analyzing the individual species indicators, such as tree species richness and bird species richness presented in *Table 7*, one may argue that this type of indicator maybe less appropriate for studying the complex relationship between temperature and biodiversity. In fact, the tree species richness seems to have strong correlation with temperature in some regions (e.g. in Mediterranean region) and in certain scenarios (e.g. A1 & B1), but the others; whereas bird species richness does not show statistical significance in most of the scenarios and regions. This result indicate that single species indicator less preferred for analyzing climate change impact on natural ecosystems, because there is limited scientific knowledge about which type of biological species is more sensitive in response to climate change and therefore higher uncertainty about the consequences on ecosystem services. However, even if we could find a species highly sensitive to temperature changes, itself will hardly have strong enough explanatory power to demonstrate that climate change can have positive or negative impacts on the ecosystem in which the species is hosted.

Table 8 Estimated socio-economic and climatic impacts on SBI & CFBI under IPCC scenarios

	LNSBI				LNCFBI			
	A1	A2	B1	B2	A1	A2	B1	B2
TSQUARE	0.0682***	0.1051***	0.1394***	0.3682***	0.0687***	0.1034***	0.1401***	0.1319***
	(0.0110)	(0.0166)	(0.0147)	(0.0504)	(0.0105)	(0.0172)	(0.0144)	(0.0251)
T_MEDI	-0.8187***	-0.9975***	-1.0845***	-2.2753***	-0.8183***	-0.9929***	-1.0843***	-1.1237***
	(0.1024)	(0.1216)	(0.0920)	(0.2452)	(0.0982)	(0.1258)	(0.0906)	(0.1164)
T_CENNORTH	-0.7010***	-0.8896***	-0.9163***	-2.1194***	-0.6918***	-0.8835***	-0.9156***	-0.8627***
	(0.1106)	(0.1294)	(0.1064)	(0.2664)	(0.1070)	(0.1339)	(0.1051)	(0.1351)
T_SCANDI	-0.5683***	-0.8155***	-0.8353***	-2.0548***	-0.5649***	-0.8081***	-0.8359***	-0.7372***
	(0.1144)	(0.1305)	(0.1003)	(0.2739)	(0.1105)	(0.1354)	(0.0990)	(0.1330)
LNPD	-2.2565***	-1.2176**	-0.3574	-0.6611	-0.6948**	-0.4016*	-0.1207	-0.0725
	(0.5245)	(0.4102)	(0.4016)	(0.5052)	(0.2213)	(0.1841)	(0.1595)	(0.0982)
LNGPC	-0.6786**	-0.4204*	-0.1156	0.1529	-2.3465***	-1.1938**	-0.3593	-1.6531***
	(0.2209)	(0.1811)	(0.1598)	(0.1226)	(0.5238)	(0.4161)	(0.4000)	(0.4476)
LNFA	-0.5914***	-0.0637	-0.2647**	0.1243	3.3246***	3.9421***	3.7250***	3.6910***
	(0.0903)	(0.1041)	(0.0953)	(0.1350)	(0.0906)	(0.1056)	(0.0941)	(0.0886)
_CONS	2.0078***	2.3151***	1.9610***	3.2611***	1.9682***	2.3107***	1.9563***	1.6934***
	(0.2484)	(0.2657)	(0.1560)	(0.3609)	(0.2401)	(0.2737)	(0.1543)	(0.2211)
N	102	102	102	102	102	102	102	102
R^2	0.8205	0.6563	0.8225	0.6392	0.9698	0.9746	0.9700	0.9760
P-VALUE	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F	167.1328	64.9551	118.5397	66.2002	1044.2537	511.5199	899.7159	1856.3990

STANDARD ERRORS IN PARENTHESES

* P<0.05, ** P<0.01, *** P<0.001

On the contrary, in ***Table 8*** both of the composite biodiversity indicators reveal to have significantly negative correlation with temperature, which in turn shows an increasing influence on biodiversity. Moreover, the marginal effects of increase in temperature are found varying across the three geo-climatic regions and in different scenarios. Take *SBI* as an example, for all three European regions, projected increase in local mean temperature will have a negative effect on the average quality of biodiversity, but the Mediterranean forest ecosystem do suffer more severer biodiversity loss from every additional degree increased in the local temperature than the Scandinavian forests. That is, 1°C increase in temperature will account for 38.8% of the decrease in biodiversity quality in the Mediterranean region, higher than 23.8% of the variation in the Scandinavian region. This result is supplementary to the recent findings of Costanza *et al.* (2007) who found a strong positive relationship between biodiversity and ecosystem productivity in higher temperature regimes. In particular, our results suggest that marginal damage of increase in temperature on biodiversity and ecosystems is expected to be greater in the warmer areas (e.g. Mediterranean) than in the cold areas (e.g. Scandinavian). Moreover, different economic and political regimes represented by four IPCC scenarios plays an essential role in determining the magnitude of climate change impact through altered biodiversity and ecosystems, which reflects ecosystem's vulnerabilities under different growing paths into the future.

Model-2 Biodiversity loss and economic effects

The second step is to model the relationship between biodiversity indicators and quantify their impacts on the marginal values of ecosystem goods and services. The dependent variable in the second model is measured as the estimated change in values that per hectare of forest can provide by 2050 under different climate change scenarios. However, due to variety of valuation methods involved in obtaining values of each type of ecosystem services (see Ding *et al.* 2009 for details) and the different nature associated with ecosystem services' values, we shall distinguish these values in terms of the types of ecosystem services and investigate the specific biodiversity effects separately. The model is expressed in a semi-log format – see Eq.(4), where changes of marginal value of ecosystem services (Vph_{EGS}) is modeled as a function of changes in a selected biodiversity indicator (BI), increases in temperature (T), changes of ecosystem coverage (fa) and the population density (pd) of the country. Note that all changes are projections up to 2050 under different future IPCC scenarios with respect to the selected baseline 2000. By including both *BI* and *ln(BI)*, we are able to model a more non-linear relationship between selected biodiversity indicators and the underpinning values of ecosystem goods and services.

$$\ln(Vph_{EGS}) = \beta_0 + \beta_1 \cdot BI + \beta_2 \cdot \ln(BI) + \beta_3 \cdot T^2 + \beta_4 \cdot T\_region + \beta_5 \cdot \ln(fa) + \beta_6 \cdot \ln(pd) + \varepsilon \text{ Eq.(4)}$$

The model was assessed using OLS[5], controlling for the types of ecosystem values. Wald test was performed to test the linear hypotheses on parameters, and the results (with all $p < 0.0000$) confirmed that the model specification has been adequately chosen for the analysis. The residuals are tested to be normally distributed using Kernel density plots. The presence of homoskedasticity is investigated by means of Breusch-Pagan test, and the obtained results reject the hypothesis of homoskedasitic distribution of the residuals at the 5% significance level. Due to the large standard errors obtained in the regression when controlling for bird species richness, we removed this biodiversity indicator from the analysis. Some of the regression results are summarized in ***Table 9*** (for the complete regression results, see table 1-3 in the Appendix).

Table 9 Estimated coefficients of biodiversity indicators

Y \ $\beta_1(X_i)$	β_1(SBI)	β_2(Ln(SBI))	β_1(CFBI)	β_2(Ln(CFBI))	β_1(NTS)	β_2(Ln(NTS))
Ln(pvph)	0.0633 (0.2694)	-0.0496 (0.3895)	0.0265 (0.0185)	-0.0227 (0.1466)	1.9017* (0.8555)	-2.3822* (1.0121)
	N=85, R^2=0.5055, P<0.0000, F=37.5299		N=85, R^2=0.5141, P<0.0000, F=33.7626		N=85, R^2= 0.5605, P<0.0000, F= 37.2480	
Ln(cvph)	0.5199 (0.3124)	-0.9727* (0.4164)	-0.0364* (0.0152)	-0.2269* (0.0994)	-0.6144 (0.5116)	0.1840 (0.5613)
	N=85, R^2=0.8572, P<0.0000, F97.5544		N=85, R^2=0.8588, P<0.0000, F=96.0795		N=85, R^2= 0.8617, P<0.0000, F=108.8206	
Ln(rvph)	0.3324 (0.1860)	-0.5468* (0.2578)	0.0325 (0.0226)	-0.1758 (0.0926)	0.0930 (0.5235)	-0.4374 (0.6117)
	N=85, R^2= 0.4595, P<0.0000 F=28.9796		N=85, R^2=0.4773, P<0.0000 F=32.8021		N=85, R^2= 0.4834, P<0.0000, F=35.0100	

Standard errors in parentheses

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Furthermore, we can use the regression model to calculate partial derivatives of *ln(Vph*$_{EGS}$*)* with respect to *BI* – see Eq.(5).

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[5] NB: The complete results of diagnostic tests are available upon request.

$$\partial \ln(Vph_{EGS}) / \partial BI = \beta_1 + \frac{\beta_2}{BI} \qquad \text{Eq.(5)}$$

The results shown in ***Table 9*** are particularly interesting when comparing the roles of different biodiversity indicators. For example, for the two composite indicators (i.e. *SBI* and *CFBI*) all β_2 carry a negative sign, which indicates that accelerated biodiversity loss due to global warming will negatively influence the changes of ecosystem values, this is particular the case for the marginal changes of cultural value. However, the magnitudes of the detected impacts turned to be very small, as all results from the regression model did not show strong statistical significance of this relationship. Moreover, our results also suggest that increasing loss of biodiversity *per se* (as shown by *SBI*) can speed up the process of losing cultural values at an increasing rate, whereas if we account for the changes in ecosystem coverage as well (as shown by *CFBI*), biodiversity loss will accelerate the lost of marginal cultural value at a slightly decreasing rate. The reason of this difference might be due to the potential effectiveness of EU forest initiatives that are oriented towards enlarging the size of exiting forest coverage and natural habitats for biodiversity conservation in the coming decades. In comparison, the biodiversity indicator at species level, i.e. tree species richness, reveals to have statistically negative relationship with the value of provisioning service, mainly timber products provided by forests. Our results suggest that losing tree species richness may negatively affect the changes of per hectare value of timber products at an increasing rate. Therefore, more effective conservation policies maybe needed in the EU to protect the diversity of tree species in forests, so as to increase the net primary productivity of the forest lands through the natural interaction between biodiversity and ecosystem.

5.3 The climate change induced biodiversity effects on ecosystem values

Since our earlier results have shown that the two composite indicators are more relevant in explaining the negative relationship between rising temperature and changes of biodiversity, we will consider them only in the present analysis. In order to understand the proportional impacts of climate change included biodiversity loss on the changes to ecosystems' values, we need to combine the results obtained from Model-1 and Model-2. The marginal effects of biodiversity changes in response to every 1°C increase in temperature were measured by the estimated β_2

coefficients in Model-1, controlling for different geo-climatic regions as well as IPCC scenarios. Incooperating these results into Eq.(5), which calculates the elasticity of value variations of ecosystem services with respect to biodiversity loss, we can obtain the proportional contribution of climate change impact on the change of annual value of all three types of ecosystem service in \$/ha, through altered biodiversity and ecosystem functioning. The computed climate change impacts are summarized in ***Table 10***. Note that since both Model-1 and 2 have detected a negative relationship, we therefore can pass on the negative sign to the relationship between climate change and the value of ecosystem services. In other words, since increasing temperature will have negative impacts on biodiversity and biodiversity loss will negatively affect the value of ecosystem services, therefore one can say that increase in temperature can have negative impacts on the value of ecosystem services.

Table 10 Comparison of the estimated climate change impacts using two composite indicators.

Types of EGS: changes of marginal value	EU Geo-climatic regions	Estimated marginal effect of climate change on the values of forest ecosystems using *SBI* under IPCC scenarios				Estimated marginal effect of climate change on the values of forest ecosystems using *CFBI* under IPCC scenarios			
		A1	A2	B1	B2	A1	A2	B1	B2
Provisioning services	Mediterranean	0.1239	0.1130	0.1090	0.0851	0.0542	0.0494	0.0474	0.0467
	Central-North	0.1341	0.1191	0.1174	0.0867	0.0593	0.0522	0.0513	0.0528
	Scandinavian	0.1506	0.1241	0.1227	0.0874	0.0667	0.0546	0.0537	0.0573
Cultural services	Mediterranean	1.7080	1.4950	1.4168	0.9474	0.2409	0.1921	0.1729	0.1655
	Central-North	1.9075	1.6133	1.5815	0.9789	0.2916	0.2204	0.2114	0.2266
	Scandinavian	2.2315	1.7127	1.6844	0.9933	0.3653	0.2444	0.2350	0.2714
Regulating services	Mediterranean	1.0003	0.8806	0.8366	0.5727	0.2473	0.2096	0.1946	0.1889
	Central-North	1.1124	0.9471	0.9291	0.5904	0.2866	0.2315	0.2245	0.2363
	Scandinavian	1.2946	1.0029	0.9870	0.5985	0.3437	0.2500	0.2428	0.2710

Generally speaking, the table results illustrate that 1°C increase of the average local temperature can contribute proportionally to the decrease of marginal value of ecosystem services, but the magnitudes of the impacts vary depending on the choice of biodiversity indicator, the types of ecosystem services, the geo-climatic region in which the ecosystem located, and the specific IPCC scenarios under consideration. However, the *CFBI* indicator is preferred in the current analysis as it presents relatively more stable results than those of the *SBI* indicator. In particular, for the cultural services, the *SBI* shows a proportional contribution of more than 100 per cent to the changes of the marginal values in all 3 regions under most of the IPCC storylines. This result seems quite odd, thus further efforts are needed to validate the model setting. Despite of this, the results from modeling the *CFBI* seem interesting and appealing. For example, under the scenario A1, 1°C increase in the temperature of the Mediterranean EU will approximately contribute to 5.4% of every one percent reduction of the value of provisioning services, 24.1% of every one percent reduction of the value of cultural services and 24.7% of every one percent reduction of the value of regulating services. This result indicates that continual increase in the temperature will have strong marginal impacts on the non-market value of Mediterranean forests, including cultural and regulating values provided by forest. However, if the society were able to implement effective policies contributing to the sustainable development, then we can then maximally mend the negative impacts of climate change on the social economy. In fact, moving away from the global economic oriented scenario A1 to the global sustainable oriented scenario B2, global warming is contributing 1 to 5 % of the reduction of the value of ecosystem services provided by Mediterranean EU. Moreover, as far as geo-climatic regions are concerned, increase in temperature is estimated to have greater influence on the percentage reduction of marginal values of ecosystem services in the Scandinavian EU than the other two regions. This means, even though the Scandinavian Europe may be observed having an economic gain due to the prolonged growing season of boreal forests, the negative impact of every degree increasing in the temperature is stronger on the value of ecosystem services at the margin. Finally, the composite indicator *CFBI* also takes into account the potential effects of enlarged ecosystem coverage as a result of different forest management regimes previously considered in the four different IPCC scenarios.

6. Concluding remarks

Our experimental investigation aimed at contributing to the research on the relationship between biodiversity and the value of ecosystem services with a specific emphasis on the climate change included biodiversity effects. Our empirical database on the future trends of population growth, economic development, future species richness and increase in local temperature was established on the best available data of climate change impact projections published by IPCC data distribution centers. Values of ecosystem services were derived from a latest study assessing the climate change impacts on forest ecosystems in Europe (Ding *et al.* 2009). Furthermore, the paper employed a two-step model to estimate the proportional impact of climate change on the proportional changes of ecosystem values through constructing two composite biodiversity indicators. Our main findings are the followings:

Firstly, our results suggest that marginal damage of increase in temperature on biodiversity and ecosystems is expected to be greater in the warmer region (e.g. Mediterranean) than in the cold areas (e.g. Scandinavian). This finding is supplementary to the recent findings of Costanza *et al.* (2007) who found a strong positive relationship between biodiversity and ecosystem productivity in higher temperature regimes. Moreover, different economic and political regimes represented by four IPCC scenarios plays an essential role in determining the magnitude of climate change impact through altered biodiversity and ecosystems, which reflects ecosystem's vulnerabilities under different growing paths into the future.

Secondly, as far as the two composite indicators (i.e. *SBI* and *CFBI*) are concerned, the composite biodiversity indicator at ecosystem level are more stable than other indicators at species level, such as the species richness, in terms of analyzing the value of ecosystem services. Our results show that accelerated biodiversity loss due to climate change will negatively influence the changes of ecosystem values in general, the changes of cultural and regulating value in particular. Among all others, the composite indicator, *CFBI* is revealed to be a proper indicator for estimating the climate change impact on ecosystem values, as it also takes into account the potential effects of enlarged or shrunk ecosystem coverage as a result of various forest management regimes previously considered in the four different IPCC scenarios.

Finally, our computation shows that increase of 1°C in the local temperature can contribute proportionally to the decrease of marginal value of ecosystem services, but the magnitudes of the impacts vary depending on the choice of biodiversity indicator, the types of ecosystem services, the geo-climatic region in which the ecosystem located, and the specific IPCC scenarios under consideration. In particular, our results suggest that continual increase in the temperature will have strong marginal impacts on the cultural value of Mediterranean forests more than other values provided by the same forests. However, if the society were able to implement effective policies contributing to the sustainable development, i.e. moving from scenario A1 to B2, we can then maximally mend the negative impacts of climate change on the social economy.

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Appendix

Table 1. Model comparison of SBI effects on EGS

	(1) lnpvph	(2) lncvph	(3) lnrvph
sbi	0.0633	0.5199	0.3324
	(0.2694)	(0.3124)	(0.1860)
lnsbi	-0.0496	-0.9727*	-0.5468*
	(0.3895)	(0.4164)	(0.2578)
tsquare	0.0046	-0.0053	0.0138*
	(0.0084)	(0.0089)	(0.0059)
t_medi	-0.0900	0.0397	-0.1935***
	(0.0456)	(0.0414)	(0.0309)
t_cennorth	-0.0517	-0.1907***	-0.1279***
	(0.0389)	(0.0360)	(0.0293)
t_scandi	0.0216	-0.1687**	-0.1682***
	(0.0569)	(0.0521)	(0.0400)
lnpd	-0.6903***	-0.2003	-0.3670
	(0.1992)	(0.1902)	(0.2208)
lnfa	-0.7724***	0.0044	-0.2969**
	(0.1320)	(0.1113)	(0.1017)
_cons	-0.0710	-0.5448	-0.3440
	(0.2655)	(0.3133)	(0.1856)
N	85	85	85
r2	0.5055	0.8572	0.4595
F	37.5299	97.5544	28.9796

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 2. Model comparison of CFBI effects on EGS

	(1) lnpvph	(2) lncvph	(3) lnrvph
cfbi	0.0265	-0.0364*	0.0325
	(0.0185)	(0.0152)	(0.0226)
lncfbi	-0.0227	-0.2269*	-0.1758
	(0.1466)	(0.0994)	(0.0926)
tsquare	0.0059	-0.0041	0.0170**
	(0.0087)	(0.0074)	(0.0059)
t_medi	-0.1060*	0.0528	-0.2180***
	(0.0503)	(0.0372)	(0.0313)
t_cennorth	-0.0640	-0.1775***	-0.1461***
	(0.0427)	(0.0337)	(0.0320)
t_scandi	0.0135	-0.1494**	-0.1772***
	(0.0617)	(0.0507)	(0.0416)
lnpd	-0.6818***	-0.1831	-0.3465
	(0.1878)	(0.1719)	(0.2186)
lnfa	-0.8792	1.1586**	0.1516
	(0.4996)	(0.3676)	(0.3512)
_cons	-0.0315	0.0158	-0.0378
	(0.0196)	(0.0207)	(0.0231)
N	85	85	85
r2	0.5141	0.8588	0.4773
F	33.7626	96.0795	32.8021

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 3. Model comparison of tree species richness effects on EGS

	(1) lnpvph	(2) lncvph	(3) lnrvph
nts_c	1.9017*	-0.6144	0.0930
	(0.8555)	(0.5116)	(0.5235)
lnnts	-2.3822*	0.1840	-0.4374
	(1.0121)	(0.5613)	(0.6117)
tsquare	-0.0003	-0.0125	0.0073
	(0.0090)	(0.0076)	(0.0070)
t_medi	-0.0969*	0.0742	-0.1708***
	(0.0464)	(0.0399)	(0.0345)
t_cennorth	-0.0332	-0.1320**	-0.0829*
	(0.0488)	(0.0390)	(0.0393)
t_scandi	0.0561	-0.1099*	-0.1140*
	(0.0644)	(0.0507)	(0.0466)
lnpd	-0.8150***	-0.2205	-0.4087
	(0.1935)	(0.1833)	(0.2303)
lnfa	-0.7536***	-0.0093	-0.3074**
	(0.1353)	(0.1083)	(0.1046)
_cons	-1.9167*	0.6041	-0.0954
	(0.8591)	(0.5126)	(0.5240)
N	85	85	85
r2	0.5605	0.8617	0.4834
F	37.2480	108.8206	35.0100

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001