# Manuscript Details

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| **Manuscript number** | ECOSER_2017_371_R1 |
| **Title** | Economic viability of the national-scale forestation program: The case of success in the Republic of Korea |
| **Short title** | Economic viability of the national-scale forestation program |
| **Article type** | Research Paper |


**Abstract**

The forests in the Republic of Korea (ROK) successfully recovered through the national forestation program as did the ecosystem services associated with them. With this positive experience, it is instructive to investigate the economic viability of the forestation program. In this study, we estimated the changes in the key ecosystem services (disaster risk reduction (DRR), carbon sequestration, water yield enhancement, and soil erosion control; 1971¬–2010) and the monetary investment of the forestation (1960¬–2010) in the ROK, at a national scale. These benefits and costs were estimated by biophysical and monetary approaches, using statistical data from several public organizations, including the Korea Forest Service and the Korea Meteorological Administration, combined with model simulation. All monetary values were converted to the present value in 2010. The net present value and the benefit-cost ratio of the forestation program were 54,316 million $ and 5.84 in 2010, respectively, in the long-term. The break-even point of the extensive investment on the forestation appeared within two decades. In particular, the enhancements of DRR and carbon sequestration were substantial. This economic viability was ensured by the subsidiary implementations (e.g., participation of villagers, shifting energy source, and administrative regulation).



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| **Keywords** | National forestation; Disaster risk reduction; Water yield; Soil erosion; Carbon sequestration; Economic viability |
| **Taxonomy** | Ecosystem Services Modeling, Quantification Ecosystem Services |



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# Submission Files Included in this PDF

**File Name  [File Type]**

Cover letter.docx  [Cover Letter]

Responses to reviewers.docx  [Response to Reviewers]

Hightlights.docx  [Highlights]

Revised Manuscript.docx  [Manuscript File]

Figure 1.tif  [Figure]

Figure 2.TIF  [Figure]

Figure 3.tif  [Figure]

Table 1.docx  [Table]

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September 25, 2017

Dear Editor:

I respectfully submit the revised research paper titled “Economic viability of the national-scale forestation program: The case of success in the Republic of Korea” to be considered for publication in *Ecosystem Services*.

The forests in the Republic of Korea successfully recovered through the national forestation program as did the forest ecosystem services. Investigation on the economic viability of the national forestation program in the long-term can provide a scientific rationale for implementation of extensive forestation in other countries, which are suffering from severe deforestation. Accordingly, we evaluated the economic viability of the forestation program during four decades at the national scale. The changes in ecosystem benefits and monetary costs were estimated by biophysical and economical approaches with statistical data and simulation models.

We have revised the manuscript in accordance with the reviewers’ comments and also prepared the responses to the comments. All the co-authors have seen and agreed with the contents of the revised manuscript and the responses to the reviewers. We certify that this paper is only submitted to *Ecosystem Services* for publication. Thank you very much for your time and consideration.

Sincerely,

Yowhan Son, Ph.D.

Professor of Korea University

## Reviewer 1

We appreciate your review of our manuscript. We have prepared responses to your comments and have revised our manuscript in accordance with these comments. Revisions to our manuscript are indicated in red font. We hope that our revised manuscript is now suitable for publication in *Ecosystem Services*.

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**[Comment 1]**
Using GDP deflation factors, instead of CPI, to convert all values to 2010 buying power.

▶**Response:** We appreciate your comment. The GDP deflator has been applied instead of the consumer price index. Consequently all the estimates of benefit and cost have been also revised throughout the manuscript.

**[Comment 2]**
Compare the ecological economic characteristics among different types of forests, and restoration or management modes, for some specific results and suggestions for practice.

▶**Response:** We appreciate your comment. Unfortunately, most of the ecosystem services in our study did not change by forest type and species. In particular, land cover (forest or not) was the main factor in determining ecosystem services by disaster risk reduction, soil erosion control, and water yield enhancement. Information on restoration and management regimen did not exist at a spatially differentiated level. However, fast-growing needle-leaved species (*Pinus* spp. and *Larix kaempferi*) were mainly planted during the forestation process. Accordingly, we have addressed it in the section of "4.3. Implications" as follows (Page 15 Lines 379–382):

"Meanwhile, the choice of plant species also had an ecological aspect. Fast-growing species (*Pinus* spp. and *Larix kaempferi*), surviving well in infertile environments, were mainly planted on the degraded lands during the national forestation program. The ecological characteristics of the species rather than their economic use improved the probability of success in the forestation program."

## Reviewer 2

We appreciate your review of our manuscript. In particular, the comments on methodologies were helpful in improving the quality of our manuscript. We have prepared responses to your comments and have revised our manuscript in accordance with these comments. Revisions to our manuscript are indicated in red font. We hope that our revised manuscript is now suitable for publication in *Ecosystem Services*.

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**[Comment 1]**
Calculating the monetary benefits of ecosystem restoration, in this case afforestation, is an important topic. Your results show that in the Korean context it was highly beneficial with a NPV of 40 billion US$ and a B/C ratio of 7.5. However, many assumptions were needed regarding methods and missing data, both on the cost side (eg. maintenance cost (400 million/y) which you left out and which were much higher than the investment costs (255/y) AND on the benefit side (you only included 4 services). This in itself is not such a big problem but the assumptions, the missing data and the implications for the results need to be clearly explained. This is where the paper needs much work still before it can be published.

▶**Response:** We appreciate your comment. We added more explanations on assumptions, missing data, and implications of the results throughout our manuscript. Particularly, we revised the method of estimating the total cost on the forestation program by using the budget of Korea Forest Service, instead of the direct cost of the forestation. Using only the direct cost of the forestation does not consider the costs of the subsidiary measures for the forestation program and its management after the forestation. Accordingly, we have revised the section of "2.2. The investment on the national forestation program" as follows (Pages 4–5 Lines 95–107):

"The monetary investment and annual costs of the forestation (1960–2010) was estimated by using the annual budget of Korea Forest Service (including plantation, protection, operation, research, and monitoring) in order to consider the cost of the initial as well as the subsidiary measures for the forestation program. The nominal value of annual investment on the forestation program was converted into a real value in 2010 Dollars by a combination of the purchasing power parity (PPP) exchange rate (Korean Won : US Dollar) and the gross domestic production (GDP) deflator, which were provided from World Bank. Finally, a constant real discount rate (i.e., net of inflation) of 3%, which is typical for forestry-type projects, was applied to this converted value in order to calculate the present value (PV) in 2010 (Treasury, 2003; Valatin, 2010; Markandya, 2014). As the information on the budget is lacking before 1981, only the direct cost of the forestation was used during the period 1960–1980. Owing to the lack of the statistical data during 1960–1972, the extrapolation was conducted by multiplying the annual planted area during 1960–1972 (65,089–454,903 ha; provided by Korea Forest Service) by unit cost of planting ($ $ha^{-1}$) in 1973."

In order to improve the implication for the benefit side, we have added the approximate portion of the other ecosystem services derived from the previous studies as follows (Pages 13–14 Lines 337–342):

"These cultural and habitat ecosystem services can account for anything between 18–62% of the total ecosystem services (de Groot et al., 2012; Kim et al., 2012). In particular, Kim et al. (2012) estimated that the annual benefit of these ecosystem services in the Republic of Korea to be up to 17 billion $ in 2008 (calculated with the PPP exchange rate). Not accounting for these services therefore means that our estimate might underestimate the total benefit of the forestation program."

**[Comment 2]**
Also the methods used are insufficiently explained, e.g., the period over which the calculations were made is unclear (I assume 1970 – 2010). It is not clear how the PV was calculated (e.g. what discount rate was used; you do mention rather late in the paper (on page 8) that you used 3% but without reference (only a statement that "this is typical for forestation projects").

▶**Response:** Thank you for pointing out these issues. We clarified the period of calculation for each component (disaster risk reduction: 1971–2010, water yield enhancement: 1971–2010, soil erosion control: 1971–2010, carbon sequestration: 1971–2010, and investment on the forestation: 1960–2010) throughout our manuscript. In addition, clear explanation on the calculation of present value (PV) was also provided to enhance understanding of potential readers.

Meanwhile, the 3% discount rate is based on rates applied to long gestation projects such as the forestry ones. The UK Forestry Commission review of discounting in forestry projects (Valatin, 2010) recommends the use of declining rates over time, following the guidance in the Treasury (2003). This guidance gives a value of 3.5% for costs and benefits over a period of 0–30 years, 3% for periods of 31–75 years and progressively decling rates thereafter. Given that this study is looking at costs and benefits over varying periods, with the longest being around 56 years (for carbon sequestration), a period of 3% seemed a reasonable approximation. We did not apply declining discount rates as in the UK recommendation as the time profile of the different benefits and costs were not always clear. In addition there are also some problems of time inconsistency with the use of decling rates (see Markandya (2014) for a discussion of these issues). Accordingly, we have provided the method of the calculation as follows:

<**Investment cost** (Pages 4–5 Lines 95–107)>

"The monetary investment and annual costs of the forestation (1960–2010) was estimated by using the annual budget of Korea Forest Service (including plantation, protection, operation, research, and monitoring) in order to consider the cost of the initial as well as the subsidiary measures for the forestation program. The nominal value of annual investment on the forestation program was converted into a real value in 2010 Dollars by a combination of the purchasing power parity (PPP) exchange rate (Korean Won : US Dollar) and the gross domestic production (GDP) deflator, which were provided from World Bank. Finally, a constant real discount rate (i.e., net of inflation) of 3%, which is typical for forestry-type projects, was applied to this converted value in order to calculate the present value (PV) in 2010 (Treasury, 2003; Valatin, 2010; Markandya, 2014). As the information on the budget is lacking before 1981, only the direct cost of the forestation was used during the period 1960–1980. Owing to the lack of the statistical data during 1960–1972, the extrapolation was conducted by multiplying the annual planted area during 1960–1972 (65,089–454,903 ha; provided by Korea Forest Service) by unit cost of planting ($ ha$^{-1}$) in 1973."

<**Benefit of carbon sequestration** (Page 5 Lines 117–121)>

"Meanwhile, the annual monetary benefit of carbon sequestration (1971–2010) was estimated by multiplying the national carbon sequestration by the social cost of carbon (31 $ ton$^{-1}$ $CO_2$; US government, 2016). The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%, which was also used in the previous section."

<**Benefit of water yield enhancement** (Page 6 Lines 137–142)>

"The annual benefit of water yield enhancement by the forestation (1971–2010) was estimated by multiplying the amount of annual water yield enhancement (the difference in water yield under the two scenarios) by the unit production cost of water (0.92 $ m$^{-3}$; considering the PPP exchange rate in 2010), announced by the Ministry of Environment in the Republic of Korea. The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%."

<**Benefit of soil erosion control** (Page 6 Lines 156–163)>

"The annual benefit of soil erosion control by the forestation (1971–2010) was estimated by multiplying amount of soil erosion control (the difference in soil erosion under the two scenarios) by the unit construction cost for a soil erosion control dam as a replacement cost (9.70 \$ $m^{-3}$; Kim et al. (2012), considering the PPP exchange rate and GDP deflator for PV in 2010). As the unit of soil erosion in the SWAT model is soil ton per hectare (ton $ha^{-1}$), the mean soil bulk density in Korean forests (1.07 g $cm^{-3}$; NIFoS, 2011) was divided to use that replacement cost. The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%."

<**Benefit of disaster risk reduction** (Page 7 Lines 188–196)>

"The level of damages from these disasters can be affected by both climate (especially for mean annual precipitation (MAP)) and forestation. In order to partition the effects of climate change and forestation and to interpolate several missing statistical data during the several decades, a regression model was developed with the above statistical data set and multiple regression analysis was carried out (Table 1; SAS, 2014). Then, the annual contribution of the forestation on DRR (benefit of DRR; 1971–2010) was estimated by comparing the monetary losses from each disaster under the forestation and the no forestation scenarios, which was also conducted for the water yield enhancement and the soil erosion control contributions in the previous section. Finally, the estimated annual benefit of DRR was converted to US Dollar PV in 2010 by applying a discount rate of 3%."

**[Comment 3]**

The monetary values of Water Yield and Erosion prevention are based on the replacement cost method (i.e. building dams). This is one of several options and it should be explained better why this one was chosen. Since you have data on the actual increase in water yield due to the afforestation program you can use, for example, the actual market value of the water. The construction cost for the hypothetical dam apparently are equivalent to 1.25\$/m3 water; if you want to use this as proxy for the value of the water yield after afforestation shouldn't you also add the maintenance costs of the dam? But, as I mentioned above I think it would have been better to use the market value of the increased water yield.

▶**Response:** We appreciate your suggestion. The production cost of water supply announced by the Korea Ministry of Environment (0.92 \$ $m^{-3}$; a proxy for the average charge for water and for its value in use), was alternatively applied to estimate the monetary value of water yield enhancement. The estimates on the benefit of water yield enhancement were also revised throughout our manuscript as follows (Page 6 Lines 137–142):

"The annual benefit of water yield enhancement by the forestation (1971–2010) was estimated by multiplying the amount of annual water yield enhancement (the difference in water yield under the two scenarios) by the unit production cost of water (0.92 \$ $m^{-3}$; considering the PPP exchange rate in 2010), announced by the Ministry of Environment in the Republic of Korea. The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%."

In the case of soil erosion control, the replacement cost method (erosion control dam (debris barrier)) had to be applied because there is no proper market value for forest soils.

**[Comment 4]**

Regarding benefits of DRR you also mention (reduced) fire risk but would more forest not lead to a higher fire risk?

▶**<u>Response:</u>** Thank you for pointing out the issue. As almost every forest fire occurs by carelessness of human in the Republic of Korea, probability of forest fire generally increased with increasing area of stocked forest area (personal communication with an expert in National Institute of Forest Science of Korea). The statistical analysis in the Table 1 also reflected this fact.

Table 1. The multiple regression models of monetary loss by disasters. Monetary loss by disasters (million \$ $yr^{-1}$) = a × stocked forest area (1,000 ha) + b × mean annual precipitation (mm $yr^{-1}$). The stocked forest area is defined as forest area, which actually contains stocking volume (Kim et al., 2017).

| **Disasters** | **Coefficient** | | $r^2$ |
|---|---|---|---|
| | **a** | **b** | |
| Landslide | - | 0.04*** | 0.43 |
| Flooding | -0.21* | 1.88*** | 0.64 |
| Forest fire | 0.002** | - | 0.13 |

*: $P < 0.10$, **: $P < 0.05$, ***: $P < 0.01$.

**[Comment 5]**

In Fig 3 the NPV is shown as a function of time but normally NPV is the total sum of costs and benefits discounted over a certain time period and just one number to compare different investments. In case this is not a mistake it needs to be explained more clearly what Fig 3 shows.

▶**Response:** We thank you very much for this comment. The time variant NPV that we show is the discounted sum of costs and benefits **up to that year**. It then varies as the time period is extended. We added more explanations on the caption in terms of the NPV and BCR. In addition, the result of sensitivity analysis on these indicators was also provided as Figure 3c in accordance with the other reviewer's suggestion. Finally, the Figure 3 and its caption were revised as follows:

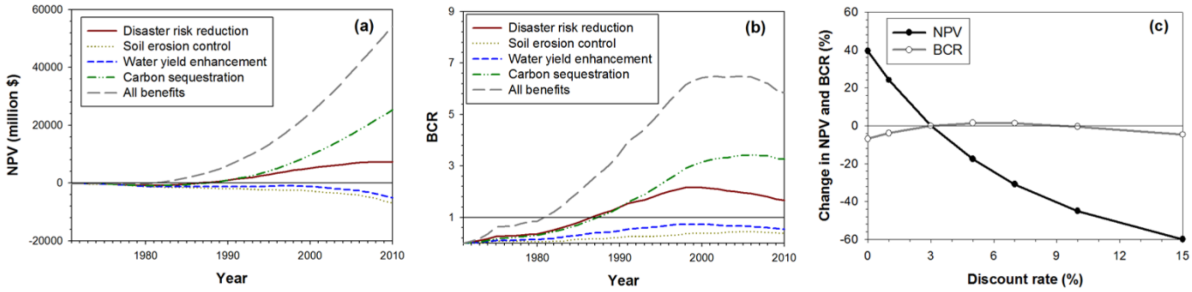


Figure 3. The (a) net present value (NPV) and (b) benefit-cost ratio (BCR) of the forestation in the Republic of Korea from 1971 to 2010, and (c) the sensitivity analysis on these indicators in 2010. The NPV and BCR for each year were calculated by compiling the benefits and costs until the year. The final NPV and BCR were shown in 2010. The NPV and BCR for each year were calculated by compiling the benefits and costs until the year. The baselines of NPV and BCR were estimated at a discount rate of 3% in the sensitivity analysis.

**[Comment 6]**

And what was the total reforested area that led to the 40 billion NPV?

▶**Response:** Thank you for your comment. As we have revised several methods for estimating the benefits and costs, the final NPV has changed. Consequently we provide the total reforested area on the sentence as follows (Page 11 Lines 269–271):

"Finally, considering all benefits the analysis exhibited a significant economic viability of the national forestation program in the long-term, showing a final NPV of 54,316 million $ in 2010, through the restoration of approximately 5 million ha."

**[Comment 7]**
Regarding the Investment costs you mention several periods on page 4 (last paragraph): 1960-1972; 2001-2010; 1973-200. And simply say you "extrapolated investment costs by multiplying unit costs in 1973 and 2000 due to lack of statistical data". This needs more detail.

▶**Response:** We appreciate your comment. We provided more explanations as follows (Page 5 Lines 105–107):

"Owing to the lack of the statistical data during 1960–1972, the extrapolation was conducted by multiplying the annual planted area during 1960–1972 (65,089–454,903 ha; provided by Korea Forest Service) by unit cost of planting ($\$$ $ha^{-1}$) in 1973."

**[Comment 8]**
Also nowhere in the paper you make clear/explicit over what time period the final NPV was calculated. On page 5 you do mention 1971 was the baseline for the Carbon-calculations but it is not clear if this was also used for the final calculations.

▶**Response:** Thank you for your comment. The final NPV was calculated from 1960, when the forestation activity started, to 2010. However, we exhibited the final NPV from 1971 because the estimations on benefits of ecosystem services by the forestation program were conducted from 1971. We clarified the time period of the final NPV in the Materials and Methods section as follows (Page 8 Lines 204–211):

"The economic viability of the forestation program was assessed by net present value (NPV) and benefit-cost ratio (BCR). In particular, the NPV and BCR for each ecosystem service and those for total ecosystem services were provided for the period 1960–2010. The NPV of the forestation program was estimated by summing the PV of the benefits from DRR and the other ecosystem functions minus sum of PV of cost. The BCR of the forestation program was simply calculated by ratio of the sum of these PV of the benefits and costs. However, we have provided these indicators only for the period 1971–2010 because the benefits of the ecosystem services were estimated only from 1971 due to the data availability."

**[Comment 9]**
All this missing information also reflects on the abstract which raises a lot of questions in its current form (it needs to be made more clear by including some of the above points).

▶**Response:** We also revised the Abstract in accordance with the response to the Comment 8 as follows (Page 2 Lines 15–23):

"In this study, we estimated the changes in the key ecosystem services (disaster risk reduction (DRR), carbon sequestration, water yield enhancement, and soil erosion control; 1971–2010) and the monetary investment of the forestation (1960–2010) in the ROK, at a national scale. These benefits and costs were estimated by biophysical and monetary approaches, using statistical data from several public organizations, including the Korea Forest Service and the Korea Meteorological Administration, combined with model simulation. All monetary values were converted to the present value in 2010. The net present value and the benefit-cost ratio of the forestation program were 54,316 million $ and 5.84 in 2010, respectively, in the long-term."

**[Comment 10]**
"using statistical data"; probably the authors mean data from statistic bureaus.

▶**Response:** The sources of the statistical data were Korea Forest Service, Korea Meteorological Administration, and other institutes. We clarified sources of statistical data as follows (Page 2 Lines 18–21):

"These benefits and costs were estimated by biophysical and monetary approaches, using statistical data from several public organizations, including the Korea Forest Service and the Korea Meteorological Administration, combined with model simulation."

**[Comment 11]**
You use 'forestation' and 'afforestation' interchangeably which is not the same; also other terms are used (eg. forest rehabilitation (p. 3, line 57) -> check entire paper for consistent use of one term

▶**Response:** Thank you for your comment. We changed other terms into "forestation" throughout our manuscript.

**[Comment 12]**
Formulate more precise; eg. on page 4, line 83 it is said that "The Korean forest cover is approx, 64% ..." ; I assume that is 'now' but since this is a paper about afforestation it would be good to state that clearly

▶**Response:** Thank you for pointing out it. We clarified it as follows (Page 4 Lines 83–84):

"The study area was the Republic of Korea. The Korean forests covered approximately 64% of the Korean territory (6,368,843 ha) in 2010 (Korea Forest Service, 2016)."

**[Comment 13]**
The next sentence on the same page (page 4, line 83-84) has, in contrast, very precise numbers on precipitation which I think are not very relevant for this paper.

▶**Response:** We simplified these numbers as follows (Page 4 Lines 84–86):

"The mean annual temperature and precipitation were approximately 11–14°C and 800–1,900 mm from 1905 to 2016, respectively (Korea Meteorological Administration (https://data.kma.go.kr/cmmn/main.do))."

**[Comment 14]**
Be careful with using significant digits; eg. on page 9 line 226: 1,553.52 etc. And are these million $/yr?

▶**Response:** Thank you for your comment. These estimates were correctly provided. We already exhibited the unit of the all estimates at the beginning of each sentence as follows (Page 10 Lines 245–246):

"The annual benefit of DRR and carbon sequestration (million \$ $yr^{-1}$) increased over time up to 1,019 and 2,778 in 2010, with averages of 464 and 614 during 1971–2010, respectively."

**[Comment 15]**

Some sections can be shortened, eg, page 3 line 65-71.

▶**Response:** Thank you for your comment. We shortened the section as follows (Pages 3–4 Lines 66–72):

"Monetary valuation directly links the ecosystems and the societies they serve, providing numerical measures of ecosystem services (Seppelt et al., 2011; Campbell and Tilley, 2014; Häyhä et al., 2015; Ruckelshaus et al., 2015). To be reliable and scientifically credible monetary valuation needs a strong basis of biophysical-based modeling, which can be based on look-up tables and simulation models (de Groot et al., 2010; Seppelt et al., 2011; Bagstad et al., 2013; Campbell and Tilley, 2014). Despite the data requirements and technical difficulties, biophysical methodologies can provide realistic estimates of forest ecosystem services (Seppelt et al., 2011; Baral et al., 2016)."

**[Comment 16]**

Fig 1 consist of 3 figures which are very small print -> better split

▶**Response:** Thank you for your comment. We improved the visibility of the Figure 1 rather than splitting as follows:

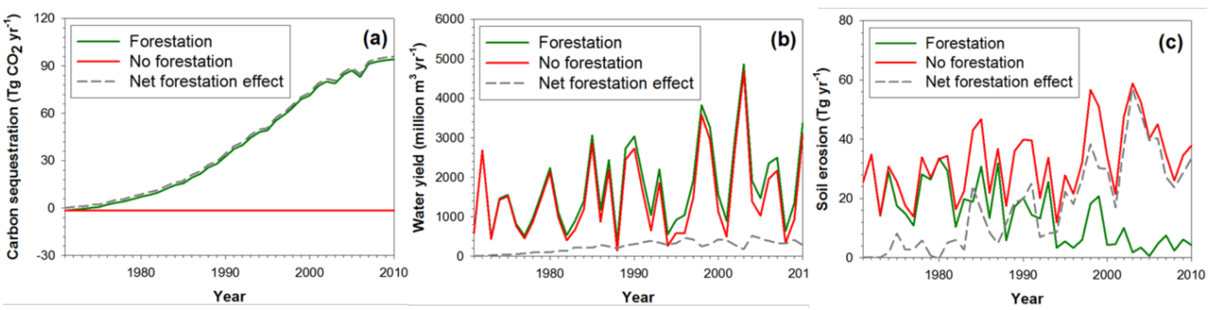


Figure 1. The biophysical output of (a) carbon sequestration, (b) water yield, and (c) soil erosion under the forestation and the no forestation scenarios. The net forestation effects were calculated by the differences in the projections of these two scenarios.

**Reviewer 3**

We appreciate your review of our manuscript. The attachment, providing specific explanation on each comment, was also really helpful. The results and discussion have been highly improved by your comments. We have prepared responses to your comments and the attached file and have revised our manuscript in accordance with these comments. Revisions to our manuscript are indicated in red font. We hope that our revised manuscript is now suitable for publication in *Ecosystem Services*.

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**[Comment 1] & [PV1 and PV2 in the attachment]**
Introduction section: Line 52-54, information on forest area counted in hectare and the increase of forest area should be provided

▶**Response:** We appreciate your comment. Statistical data on the total forest area did not show significant change due to the criteria of classifying land use (e.g., 6,415,419ha in 1952 (before the Korean War) → 6,334,615 ha in 2015; Korea Forest Service, 2016). For this reason, it is impossible to show the magnitude of the deforestation throughout the history with the statistical data of forest area. Instead, the increase in mean stand volume ($m^3$ $ha^{-1}$) by the forestation program, which can also show the deforesatation and the following success in the forestation program quantitatively, were provided as follows (Page 3 Lines 54–57):

"The Korean government implemented the national forestation program from the 1960s and the Korean forests successfully recovered during the subsequent decades (Korea Forest Service, 2014; Park et al., 2017). Subsequently, the mean stand volume density ($m^3$ $ha^{-1}$) increased from 9.55 in 1960 to 145.99 in 2015 (Korea Forest Service, 2016)."

**[Comment 2] & [PV3 in the attachment]**
Materials and methods: I) should provide forest area in hectare and the year of publishing data

▶**Response:** We appreciate your comments. We added the information as follows (Page 4 Lines 83–84):

"The study area was the Republic of Korea. The Korean forests cover approximately 64% of the Korean territory (6,368,843 ha) in 2010 (Korea Forest Service, 2016)."

**[Comment 3] & [PV3 in the attachment]**
should provide information on soil type and forest management practices

▶**Response:** We appreciate your comments. We added the information as follows (Page 4 Lines 88–90):

"The forest soils mainly consist of Entisol and Inceptisol in the Republic of Korea (Brady and Weil, 2008). The Korean forests have been mainly managed by tending work and protection."

**[Comment 4] & [PV4 in the attachment]**
should provide total planted area and investment by 2 periods (1960-1972 & 2001-2010);

▶**Response:** We appreciate your comments. The investment during these two periods did not exist, except for the planted area. The extrapolation of the direct cost of the forestation (e.g., planting and protecting) during the latter period was deleted in accordance with the response to another reviewer's comment. We clarified the process of extrapolating the investment and provided the additional information during the period as follows (Page 5 Lines 105–107):

"Owing to the lack of the statistical data during 1960–1972, the extrapolation was conducted by multiplying the annual planted area during 1960–1972 (65,089–454,903 ha; provided by Korea Forest Service) by unit cost of planting ($\$$ $ha^{-1}$) in 1973."

You also commented whether there was record of survival rate on the planting in the attached file. Unfortunately, we were not able to provide it because there is no data.

**[Comment 5] & [PV5 and PV6 in the attachment]**
provide explanation on using one unit costs for estimating environmental benefits (i.e. SC-carbon, erosion etc.) for whole accounting periods; need to check the SC -carbon with SC-carbon reported in technical report of Interagency Working Group on Social Cost of Greenhouse Gases, United States Government (2016)

▶**Response:** We appreciate your suggestion. We applied the average of social cost of $CO_2$ at discount rate of 3% (31 $\$$ per metric ton $CO_2$) in the reference. The explanation on estimating ecosystem service benefit of carbon sequestration was also revised as follows (Page 5 Lines 117–121):

"Meanwhile, the annual monetary benefit of carbon sequestration (1971–2010) was estimated by multiplying the national carbon sequestration by the social cost of carbon (31 $\$$ $ton^{-1}$ $CO_2$; US government, 2016). The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%, which was also used in the previous section."

You also commented that using the replacement cost of erosion control dam for estimating the benefit of soil erosion control needed to be changed. There were several options for preventing soil erosion (e.g., sodding, masonry, and other facilities). Although Korea Forest Service provided the table of quantity per unit for each option, standardizing costs of each option was difficult. The replacement cost of constructing a soil erosion control dam in our manuscript was the result of standardizing replacement cost, conducted by the National Institute of Forest Science in the Republic of Korea (Kim et al., 2012). In addition, there is no proper market value for forest soils, therefore, we have not changed the replacement cost.

**[Comment 6] & [PV7 in the attachment]**
consider to apply different practical options for discount rates for sensitivity analysis.

▶**Response:** We appreciate your suggestion. The sensitivity analysis was conducted on the final NPV and BCR in 2010, varying the discount rate (0–15%). The process of the sensitivity analysis were provided in the Materials and Methods section (2.5. Economic viability of the forestation program) as follows (Page 8 Lines 211–214):

"Furthermore, sensitivity analysis on the NPV and BCR in 2010 (at a discount rate of 3%) was also conducted, varying the discount rate (0–15%). The NPV and BCR by altering the discount rate were compared with these estimates at the rate of 3% and then their differences were provided as a unit of percentage."

The results were provided as follows (Page 11 Lines 284–289):
"The sensitivity of the results to the discount rate showed the final NPV in 2010 to be sensitive to that parameter (Figure 3c). The NPV changed by 39.3% (discount rate = 0%) and by -59.9% (discount rate = 15%) from the NPV at a rate of 3% by varying the discount rate. Particularly, the NPV at the discount rate of 15% was 22 billion $, still showing an economic viability of the forestation program. Meanwhile, the BCR responded much less to the change in discount rate, showing only a small range of change (-7.3–1.6%). "

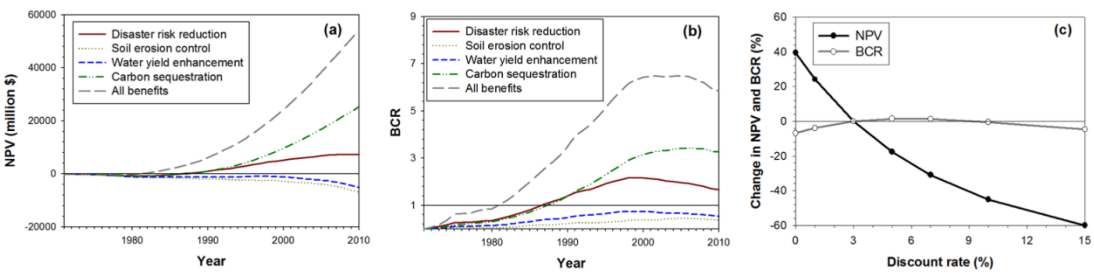


Figure 3. The (a) net present value (NPV) and (b) benefit-cost ratio (BCR) of the forestation in the Republic of Korea from 1971 to 2010, and (c) the sensitivity analysis on these indicators in 2010. The NPV and BCR of each year were calculated by compiling the benefit and cost until the year. The final NPV and BCR were shown in 2010. The NPV and BCR for each year were calculated by compiling the benefits and costs until the year. The baselines of NPV and BCR were estimated at a discount rate of 3% in the sensitivity analysis.

We also added a discussion on the sensitivity analysis as follows (Page 14 Lines 348–357):

"Our study suggests that an extensive forestation program such as the one in the Republic of Korea is very beneficial, showing high economic viability in the long-term. This high economic viability contributes to sustainable development. Recovery of forests conserves forest ecosystems and generates economic benefits to society. In particular, these economic benefits do not give burden to ecosystems, compared to some conventional development policies. The result of sensitivity analysis also showed that the indicators of economic viability were positive for a wide range of discount rates. It implied that the long-term economic viability of forestation would be ensured regardless of view taken on the appropriate rate. Our estimate especially provides a valuable reference on successful forestation program for developing countries, which encounter conflicts on land-use of forest land between utilization and conservation (Mutoko et al., 2015)."

**[Comment 7] & [PV8 in the attachment]**

Results: I) section 4.1 should provide description of potential uncertainties (inputs data, method, qualitative assessment)

▶**Response:** We appreciate your comment. We addressed the potential uncertainties section as follows (Page 12 Lines 303–315):

"There are potential uncertainties in input data and analytic tools (biophysical ecosystem models and multiple regression model) for the biophysical assessment (Table 2). The biophysical models used for simulating carbon sequestration, soil erosion, and water yield, have been verified for the Republic of Korea in previous work (Lee et al., 2014; Kim et al., 2017). These verifications limit the uncertainty in the biophysical models. The input data of these models was also considered to be reliable given the reliable sources they came from (authorized public organizations) and the high spatial resolution. Although the multiple regression models of the disaster damages were developed by the national statistics (Table 1), there were some sources of uncertainty: basis of assumptions and limitation on spatial projection. Despite these uncertainties, we consider these results to be generally reliable because the result of each component of ecosystem services (DRR, carbon sequestration, water yield, and soil erosion) was estimated with the most comprehensive statistical data and the verified simulation models for the Republic of Korea (Lee et al., 2014; Kim et al., 2017)."

Table 2. The source and level of uncertainty in the biophysical assessment.

| Category | Level of uncertainty | Notes |
|---|---|---|
| Biophysical models (carbon sequestration, soil erosion, water yield) | Low | Verified models for the forests in the Republic of Korea (Lee et al., 2014; Kim et al., 2017) |
| Input data of the biophysical models | Low | Derived from the reliable statistical data; High quality of spatial resolution (1 $km^2$) |
| Multiple regression model (disaster risk reduction) | Medium | Derived from the reliable statistical data; Based on several assumptions Limitation on spatial projection |

**[Comment 8] & [PV11 in the attachment]**
section 4.3, it would be good to discuss implication of integration of environmental services value in the national statistics (forest account) for policy option

▶**Response:** We appreciate your suggestion. We added a new paragraph in the section of "4.3. Implications" as follows (Page 14 Lines 358–364):

"Furthermore, our approach of quantifying ecosystem services at the temporal and spatial scales can also support the implementation of environmental policy. Many countries underestimate economic values of forest ecosystems, not internalizing these values, owing to a lack of quantitative assessments. This phenomenon disregards the role of forests among land-use types. Providing the methodological framework and the high economic value of forest ecosystems can integrate forest ecosystem services into decision-making processes, contributing to implementation of optimal land-use policy."

***Other comments in the attached file***

**Comment [PV9]**

This is good and it shows numbers of ecosystem services are not captured since data unavailability. Therefore, it should state somewhere about the scope of this study in term of economic valuation of reforestation program.

▶**Response:** We appreciate your comment. We addressed the point as follows (Page 13 Lines 328–330):

"In contrast, the benefits of the forestation program are underestimated because only four ecosystem services were included in this study due to the low data availability."

**Comment [PV10]**

This value is important, is there any data for valuing this? Or there is no charge for recreation activities in the forests?

▶**Response:** We appreciate your comment. We added the information as follows (Pages 13–14 Lines 337–342):

"These cultural and habitat ecosystem services can account for anything between 18–62% of the total ecosystem services (de Groot et al., 2012; Kim et al., 2012). In particular, Kim et al. (2012) estimated that the annual benefit of these ecosystem services in the Republic of Korea to be up to 17 billion $ in 2008 (calculated with the PPP exchange rate). Not accounting for these services therefore means that our estimate might underestimate the total benefit of the forestation program."

**Comment [PV12]**

This is good, but how it would be calculated and integrated in the policy?

▶**Response:** Thank you for pointing out this issue. We have integrated them by using the annual budget of Korea Forest Service (1960–2010) in the revised manuscript.

## References for the responses to the reviewers' comments

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**Highlights**

- The Republic of Korea (ROK) succeeded in its goal of national forestation.
- The economic viability of the forestation program in the ROK was investigated.
- The net present value and benefit-cost ratio were 54,316 million $ and 5.84.
- This economic viability was supported by additional measures for the forestation.
- Extensive and early investment in forestation is recommended for other countries.

# Economic viability of the national-scale forestation program: The case of success in the Republic of Korea

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**Abstract**

The forests in the Republic of Korea (ROK) successfully recovered through the national forestation program as did the ecosystem services associated with them. With this positive experience, it is instructive to investigate the economic viability of the forestation program. In this study, we estimated the changes in the key ecosystem services (disaster risk reduction (DRR), carbon sequestration, water yield enhancement, and soil erosion control; 1971–2010) and the monetary investment of the forestation (1960–2010) in the ROK, at a national scale. These benefits and costs were estimated by biophysical and monetary approaches, using statistical data from several public organizations, including the Korea Forest Service and the Korea Meteorological Administration, combined with model simulation. All monetary values were converted to the present value in 2010. The net present value and the benefit-cost ratio of the forestation program were 54,316 million $ and 5.84 in 2010, respectively, in the long-term. The break-even point of the extensive investment on the forestation appeared within two decades. In particular, the enhancements of DRR and carbon sequestration were substantial. This economic viability was ensured by the subsidiary implementations (e.g., participation of villagers, shifting energy source, and administrative regulation). Early and extensive investment in forestation is recommended for economic viability and successful implementation of the program. Our study is expected to provide a scientific rationale for implementing forestation program in other countries.

**Highlights**

- The Republic of Korea (ROK) succeeded in its goal of national forestation.
- The economic viability of the forestation program in the ROK was investigated.
- The net present value and benefit-cost ratio were 54,316 million $ and 5.84.
- This economic viability was supported by additional measures for the forestation.
- Extensive and early investment in forestation is recommended for other countries.

**Keywords:** National forestation; Disaster risk reduction; Water yield; Soil erosion; Carbon sequestration; Economic viability

## 1. Introduction

Forest ecosystems can provide a substantial amount of ecosystem services, which consist of provisioning, regulating, habitat or supporting, and cultural services (TEEB, 2010). Global society has paid attention to these forest ecosystem services, which approximately account for 125–145 trillion US Dollar $yr^{-1}$ (Costanza et al., 2014). Deforestation activities, however, have threatened the forest ecosystem services and conflicts of interest always exist between conservation and utilization (DeFries et al., 2010; TEEB, 2010; Mutoko et al., 2015). Given the substantial value of forest ecosystem services, forestation activities are potentially highly beneficial to human society. In this context, estimating the value of these services can aid in internalizing the benefits for forestation. The internalization might be also help to support ecosystem-based financing for environmental policies (de Groot et al., 2010; Campbell and Tilley, 2014; Baral et al., 2016). Thus, valuation of forestation through its ecosystem services is a timely topic for supporting the implementation of forest management policies.

The Republic of Korea experienced severe deforestation after the Korean War, when more than half of the forests were destroyed. The Korean government implemented the national forestation program from the 1960s and the Korean forests successfully recovered during the subsequent decades (Korea Forest Service, 2014; Park et al., 2017). Subsequently, the mean stand volume density ($m^3$ $ha^{-1}$) increased from 9.55 in 1960 to 145.99 in 2015 (Korea Forest Service, 2016). The success of the program is especially unique for the following reasons: 1) the Republic of Korea is one of only four countries which succeeded in post-war forest rehabilitation and 2) the Republic of Korea is the only developing country among these countries (the others being Germany, the UK and New Zealand, Gregersen, 1982). This positive experience of forestation can be instructive to examine which ecosystem services benefitted from the national forestation. In particular, assessing the economic viability of the national forestation program in the Republic of Korea can provide a reliable scientific rationale of forestation program in other countries where the forests have been suffered from deforestation.

Monetary valuation directly links the ecosystems and the societies they serve, providing numerical measures of ecosystem services (Seppelt et al., 2011; Campbell and Tilley, 2014; Häyhä et al., 2015; Ruckelshaus et al., 2015). To be reliable and scientifically credible monetary valuation needs a strong basis of biophysical-based modeling, which can be based on look-up tables and simulation models (de Groot et al., 2010; Seppelt et al., 2011; Bagstad et al., 2013; Campbell and Tilley, 2014). Despite the data requirements and technical difficulties, biophysical methodologies can provide realistic estimates of forest ecosystem services (Seppelt et al., 2011; Baral et al., 2016).

In this study, we evaluate the changes in the ecosystem services (disaster risk reduction

(DRR), carbon sequestration, water yield enhancement, and soil erosion control) and the monetary investment and associated other costs of the national forestation program in the Republic of Korea. All ecosystem services (biophysical and monetary value) and the investments in the forestation program were estimated through a combination of statistical data and modeling approaches. Following on from that we determined the economic viability of the national forestation program, which can be crucial information to other countries in the world looking into forestation options.

## 2. Materials and Methods

### 2.1. Study area

The study area was the Republic of Korea. The Korean forests cover approximately 64% of the Korean territory (6,368,843 ha) in 2010 (Korea Forest Service, 2016). The mean annual temperature and precipitation from 1905 to 2016 were approximately 11–14°C and 800–1,900 mm, respectively (Korea Meteorological Administration (https://data.kma.go.kr/cmmn/main.do)). The forest types consist of coniferous forests (32.1%), deciduous forests (39.0%), and mixed forests (28.9%) (NIFoS, 2011). The forest soils mainly consist of Entisol and Inceptisol in the Republic of Korea (Brady and Weil, 2008). The Korean forests has been mainly managed by tending work and protection. The Korean forests have been mainly managed by tending work and protection. Most of the forests are located below the elevation of 600 m.a.s.l (NIFoS, 2011). The forest area with steep slope (> 30°) accounts for approximately a half of the total forest area (NIFoS, 2011).

### 2.2. The investment on the national forestation program

The monetary investment and annual costs of the forestation (1960–2010) was estimated by using the annual budget of Korea Forest Service (including plantation, protection, operation, research, and monitoring) in order to consider the cost of the initial as well as the subsidiary measures for the forestation program. The nominal value of annual investment on the forestation program was converted into a real value in 2010 Dollars by a combination of the purchasing power parity (PPP) exchange rate (Korean Won : US Dollar) and the gross domestic production (GDP) deflator, which were provided from World Bank. Finally, a constant real discount rate (i.e., net of inflation) of 3%, which is typical for forestry-type projects, was applied to this converted value in order to calculate the present value (PV) in 2010 (Treasury, 2003; Valatin, 2010; Markandya, 2014). As the information on the budget is lacking before 1981, only the direct cost of the forestation was used during the period

1960–1980. Owing to the lack of the statistical data during 1960–1972, the extrapolation was conducted by multiplying the annual planted area during 1960–1972 (65,089–454,903 ha; provided by Korea Forest Service) by unit cost of planting ($ $ha^{-1}$) in 1973.

### 2.3. The benefit of carbon sequestration, water yield enhancement and soil erosion control with modeling approach

A Korean-specific forest carbon model, the Forest Biomass and Dead Organic Matter Carbon (FBDC) model, was developed to simulate annual carbon dynamics (Lee et al. 2014). This model already quantified the carbon dynamics in various forest ecosystems (Lee et al. 2014, 2016, 2017). In particular, Lee et al. (2014) estimated annual total forest carbon stocks from 1954 to 2012 at a national scale with the FBDC model and these estimates and methodologies were also verified externally. Accordingly, the modeling methodologies in Lee et al. (2014) were directly used to simulate the annual carbon sequestration at a national scale in this study. Meanwhile, the annual monetary benefit of carbon sequestration (1971–2010) was estimated by multiplying the national carbon sequestration by the social cost of carbon (31 $ $ton^{-1}$ $CO_2$; US government, 2016). The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%, which was also used in the previous section. Then the benefits in 1971 (baseline) were subtracted from the annual benefits during 1971–2010 to partition the net effect of forestation on enhancement of carbon sequestration.

The Integrated Valuation of Ecosystem Services and Tradeoff (InVEST) model was applied to quantify ecosystem services in a spatial unit (Sharp et al., 2015). In particular, the InVEST Water Yield (InVEST-WY) model is able to estimate annual amount of water supply by land cover (Song et al., 2015). InVEST-WY requires data on annual precipitation, potential evapotranspiration, depth-to-root restricting layer, plant's available water content, land use and watersheds, and biophysical table. The seasonality factor should be also adjusted to study region. This parameterization process followed the methodologies in Kim et al. (2017), which already simulated the annual water yield in the Republic of Korea with the verified methodologies and model estimates.

Following this, the net effect of forestation on water yield enhancement was estimated by a comparison of annual model projections under two scenarios: a forestation scenario and a no forestation scenario. In the forestation scenario, the change in forest area through the forestation program and other factors were reflected. In contrast, the no forestation scenario excluded the change in forest area by the forestation program. The difference in water yield between these two scenarios was the net effect of the forestation on water yield enhancement. The annual benefit of water yield enhancement by the forestation (1971–2010) was estimated by multiplying the amount of annual water yield enhancement (the difference in water yield under the two scenarios) by the unit production cost of water (0.92 \$ $m^{-3}$; considering the PPP exchange rate in 2010), announced by the Ministry of Environment in the Republic of Korea. The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%.

The Soil and Water Assessment Tool (SWAT) is a semi-distributed model and a hydrological model, which is able to simulate amount of soil erosion with a basis on hydrologic response unit (HRU) (Gassman et al., 2007). The Modified Universal Soil Loss Equation (MUSLE), a module of the SWAT model, was used to estimate soil erosion in the SWAT model. The MUSLE is widely used to simulate soil erosion around the world (William, 1975). It has an advantage in reflecting the energy flow of surface runoff. In this equation, factors such as rainfall, slope, vegetation, conservation management are required. In addition, digital elevation model (DEM), land cover, soil data, and weather data were used as input data for the simulation. This parameterization process followed the methodologies in Kim et al. (2017), which already simulated the annual soil erosion in the Republic of Korea with the verified methodologies and model estimates.

The net effect of the forestation on soil erosion control was then estimated by comparing annual model projections under two different scenarios (forestation scenario and no forestation scenario), which were identical to the case of water yield enhancement. The difference in soil erosion between these two scenarios was net effect of the forestation on soil erosion control. The annual benefit of soil erosion control by the forestation (1971–2010) was estimated by multiplying amount of soil erosion control (the difference in soil erosion under the two scenarios) by the unit construction cost for a soil erosion control dam as a replacement cost (9.70 \$ $m^{-3}$; Kim et al. (2012), considering the PPP exchange rate and GDP deflator for PV in 2010). As the unit of soil erosion in the SWAT model is soil ton per hectare (ton $ha^{-1}$), the mean soil bulk density in Korean forests (1.07 g $cm^{-3}$; NIFoS, 2011) was divided to use that replacement cost. The annual benefit was then converted to US Dollar PV in 2010 by applying a discount rate of 3%. As the unit of soil erosion in the SWAT model is soil ton per hectare (ton $ha^{-1}$), the mean soil bulk density in Korean forests (1.07 g $cm^{-3}$; NIFoS, 2011) was divided to use that replacement cost.

## 2.4. Benefits of DRR

The data of monetary damage from disasters (landslide, flooding and forest fire) were collected from various data sources. The Korea Forest Service provides data of forest area and casualties damaged by landslides from 1976 to 2010, except for 1983 and 1992. To obtain the costs of recovery in individual years, unit cost of recovery from landslide in 2010 (≒ 0.11 million US Dollar $ha^{-1}$; Korea Forest Service) was applied. By multiplying the estimated unit cost of recovery by damaged area from landslide, the annual monetary damage was estimated from 1976 to 2010. Then the annual damages of landslide were converted to monetary value in 2010 by using the GDP deflator and the PPP exchange rate.

The Water Resource Management Information System (WAMIS) of the Republic of Korea has the most comprehensive data of damage by flooding in the Republic of Korea from 1971 to 2010, except for 2007. The damages on human lives, area, and assets, such as buildings, ships, croplands, public infrastructures, are annually provided by at the regional scale. The monetary damage by flooding was directly calculated by summing the damages to assets. The annual damages by flooding were converted to monetary value in 2010 by using the GDP deflator and PPP exchange rate in each year.

Meanwhile, the Statistical Yearbook of Forestry reported by Korea Forest Service, provides annual data of damaged area (1984–2010), volume (1968–2010), and monetary loss (1980–2010) by forest fire. The annual monetary loss was converted to monetary value in 2010 using the GDP deflator and the PPP exchange rate. Then, the monetary loss before 1979 was extrapolated by a regression model of the monetary loss with respect to damaged area, using the monetary value of these damages during 1980–2010.

The level of damages from these disasters can be affected by both climate (especially for mean annual precipitation (MAP)) and forestation. In order to partition the effects of climate change and forestation and to interpolate several missing statistical data during the several decades, a regression model was developed with the above statistical data set and multiple regression analysis was carried out (Table 1; SAS, 2014). Then, the annual contribution of the forestation on DRR (benefit of DRR; 1971–2010) was estimated by comparing the monetary losses from each disaster under the forestation and the no forestation scenarios, which was also conducted for the water yield enhancement and the soil erosion control contributions in the previous section. Finally, the estimated annual benefit of DRR was converted to US Dollar PV in 2010 by applying a discount rate of 3%.

Table 1. The multiple regression models of monetary loss by disasters. Monetary loss by disasters (million \$ $yr^{-1}$) = a × stocked forest area (1,000 ha) + b × mean annual precipitation (mm $yr^{-1}$). The stocked forest area is defined as forest area, which actually contains stocking volume (Kim et al., 2017).

| Disasters | Coefficient | | $r^2$ |
|---|---|---|---|
| | a | b | |
| Landslide | - | 0.04*** | 0.43 |
| Flooding | -0.21* | 1.88*** | 0.64 |
| Forest fire | 0.002** | - | 0.13 |

*: $P < 0.10$, **: $P < 0.05$, ***: $P < 0.01$.

### 2.5. Economic viability of the forestation program

The economic viability of the forestation program was assessed by net present value (NPV) and benefit-cost ratio (BCR). In particular, the NPV and BCR for each ecosystem service and those for total ecosystem services were provided for the period 1960–2010. The NPV of the forestation program was estimated by summing the PV of the benefits from DRR and the other ecosystem functions minus sum of PV of cost. The BCR of the forestation program was simply calculated by ratio of the sum of these PV of the benefits and costs. However, we have provided these indicators only for the period 1971–2010 because the benefits of the ecosystem services were estimated only from 1971 due to the data availability. Furthermore, sensitivity analysis on the NPV and BCR in 2010 (at a discount rate of 3%) was also conducted, varying the discount rate (0–15%). The NPV and BCR by altering the discount rate were compared with these estimates at the rate of 3% and then their differences were provided in percentage terms.

## 3. Results

### 3.1. The biophysical changes in carbon sequestration, water yield, and soil erosion

The biophysical assessments to carbon sequestration, water yield, and soil erosion showed that scenario comparison had an advantage in partitioning the net effect of the forestation on ecosystem services (Figure 1). The carbon sequestration (Tg $CO_2$ $yr^{-1}$) significantly increased with time due to the maturity of the forests ($P < 0.05$), increasing from -1.69 in 1971 to 93.98 in 2010 under the forestation scenario (Figure 1a). The net effect of the forestation on carbon sequestration was estimated by subtracting the projection of the no forestation scenario (-1.69 Tg $CO_2$ $yr^{-1}$) from the projection of the forestation scenario. Accordingly, the net effect of the forestation also increased with time, up to 95.67 Tg $CO_2$ $yr^{-1}$ in 2010.

In contrast, water yield did not show a significant trend with time passage under the forestation scenario ($P > 0.05$) while the net effect of forestation was partitioned (Figure 1b). The water yield (million $m^{-3}$ $yr^{-1}$) ranged from 340.63 to 4,860.37 with an average of 1,759.75 under the forestation scenario. The no forestation scenario exhibited the water yield with a range of 591.35–1,106.88 million $m^{-3}$ $yr^{-1}$. The net effect of the forestation on water yield enhancement showed a gradual increase with time passage (11.01–521.54 million $m^{-3}$ $yr^{-1}$).

Meanwhile, soil erosion (million $m^{-3}$ $yr^{-1}$) decreased with time ($P < 0.05$) from 23.9 in 1971 to 3.96 in 2010 under the forestation scenario (Figure 1c). There was also a substantial annual variation due to the sensitivity of soil erosion to climate (e.g., precipitation). By comparing the projection of the forestation with the no forestation scenario, the net effect of the forestation (million $m^{-3}$ $yr^{-1}$) was estimated, ranging from 0.07 to 3.39.

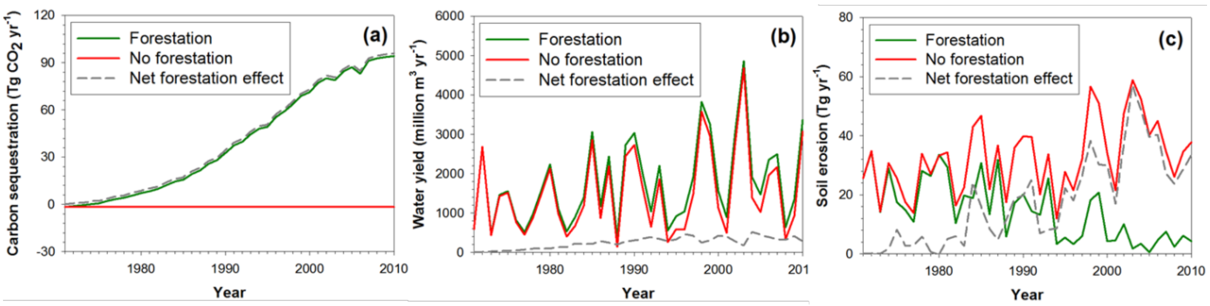


Figure 1. The biophysical output of (a) carbon sequestration, (b) water yield, and (c) soil erosion under the forestation and the no forestation scenarios. The net forestation effects were calculated by the differences in the projections of these two scenarios.

### 3.2. The annual benefit of ecosystem services by forestation and the annual investment on

**forestation**

The annual monetary benefit of each ecosystem service by the forestation surpassed the investment on the forestation program in the long-term (Figure 2). In particular, the benefits of DRR and carbon sequestration accounted for most of the enhanced ecosystem services by the forestation program. The annual benefits of DRR and carbon sequestration (million \$ $yr^{-1}$) increased over time up to 1,019 and 2,778 in 2010, with averages of 464 and 614 during 1971–2010, respectively. The other ecosystem services, water yield and soil erosion control also increased as a result of the forestation program. The annual benefit of water yield enhancement and soil erosion control (million \$ $yr^{-1}$) increased over time up to 263 and 278 in 2010, with the averages of 107 and 152 during 1971–2010, respectively. Finally, the annual benefits (million \$ $yr^{-1}$) of DRR, carbon sequestration, water yield enhancement, and soil erosion control were 1,019 (23.5% of the total), 2,778 (64.0%), 263 (6.1%), and 278 (6.4%) in 2010, respectively.

Meanwhile, the annual investment on the forestation program was 220 million \$ $yr^{-1}$ on average from 1960 to 2010 (Figure 2). The investment started increasing after the start of the forestation from 1970s. Particularly, the investment was especially concentrated after 2000, the time after the success of the national forestation program in the Republic of Korea, with the average of 647 million \$ $yr^{-1}$.

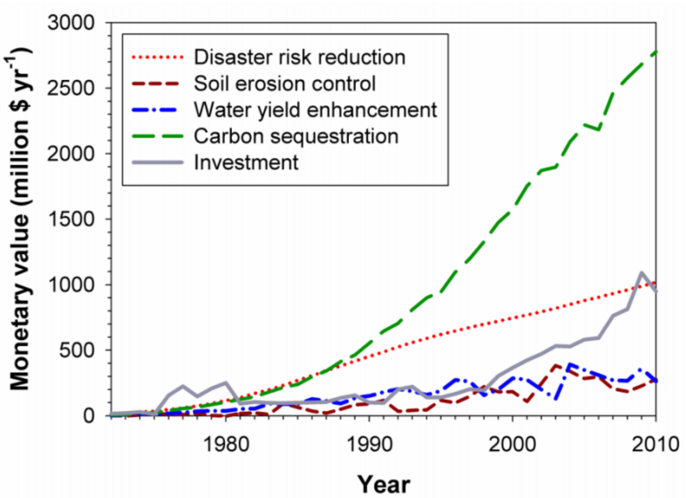


Figure 2. The annual benefit of the enhanced ecosystem services by the forestation and the annual monetary investment on the forestation. All monetary values were converted into present monetary values in 2010 US Dollars.

**3.3. Total economic assessment**

The NPV of each ecosystem service showed that consideration of diverse ecosystem services demonstrates the economic viability of the national forestation program in the long-term (Figure 3a). The forestation program was economically viable with DRR or carbon sequestration (NPV > 0) alone, generating more than 7,000 million $ NPV for each in 2010. The break-even point appeared in 1987 and 1988 for DRR and carbon sequestration, respectively. In contrast, considering only water yield enhancement and soil erosion control cannot establish the economic viability of the forestation program (NPV < 0). Finally, considering all benefits the analysis exhibited a significant economic viability of the national forestation program in the long-term, showing a final NPV of 54,316 million $ in 2010, through the restoration of approximately 5 million ha.

The benefit of DRR, carbon sequestration, water yield enhancement, and soil erosion control among the total NPV in 2010 accounted for 28.3%, 6.6%, 9.3%, and 55.8%, respectively. In addition, the consideration of all benefits shortened the break-even point of the forestation program (in 1981), which was earlier than the cases of considering only carbon sequestration and DRR.

The BCR of the forestation program ranged from 0.38 to 5.84 in the long-term, varying with the number of considered ecosystem services (Figure 3b). The case of considering only the benefit of soil erosion control showed lowest BCR, less than 0.47 during the decades. With consideration of all the benefits, the BCR increased from 0.07 in 1972 to 5.84 in 2010, showing a high economic viability of the forestation program. In particular, the BCR for DRR, carbon sequestration, water yield enhancement, and soil erosion control were 1.66, 0.38, 0.54, and 3.26 in 2010, respectively. Consequently, the BCR of the national forestation program would place in the range of those minimum and maximum of the BCR in accordance with combination of the ecosystem services.

The sensitivity of the results to the discount rate showed the final NPV in 2010 to be sensitive to that parameter (Figure 3c). The NPV changed by 39.3% (discount rate = 0%) and by -59.9% (discount rate = 15%) from the NPV at a rate of 3% by varying the discount rate. Particularly, the NPV at the discount rate of 15% was 22 billion $, still showing an economic viability of the forestation program. Meanwhile, the BCR responded much less to the change in discount rate, showing only a small range of change (-7.3–1.6%).

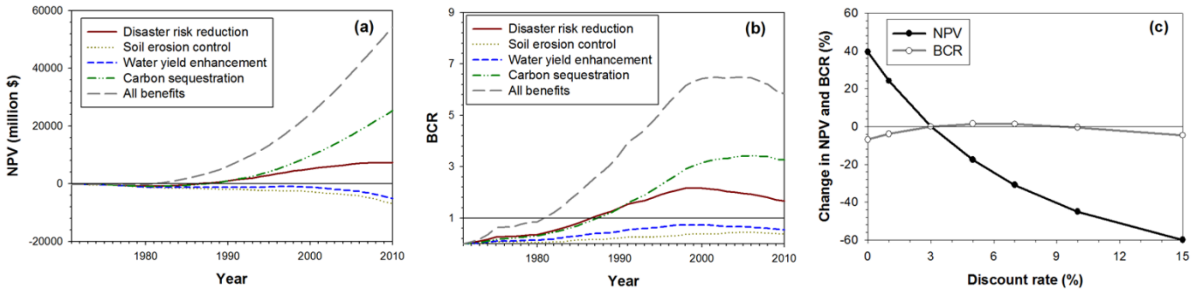


Figure 3. The (a) net present value (NPV) and (b) benefit-cost ratio (BCR) of the forestation in the Republic of Korea from 1971 to 2010, and (c) the sensitivity analysis on these indicators in 2010. The NPV and BCR for each year were calculated by compiling the benefits and costs until the year. The final NPV and BCR were shown in 2010. The NPV and BCR for each year were calculated by compiling the benefits and costs until the year. The baselines of NPV and BCR were estimated at a discount rate of 3% in the sensitivity analysis.

## 4. Discussion

### 4.1. Reliability of the biophysical and economic assessment

This study investigated the biophysical and economic impacts of the national forestation program in the Republic of Korea. The program was found to be economically viable in the long-term. The break-even point, where the investment on the forestation started being economically viable, appeared within a decade of the start of the extensive program during the 1970s. There are potential uncertainties in input data and analytic tools (biophysical ecosystem models and multiple regression model) for the biophysical assessment (Table 2). The biophysical models used for simulating carbon sequestration, soil erosion, and water yield, have been verified for the Republic of Korea in previous work (Lee et al., 2014; Kim et al., 2017). These verifications limit the uncertainty in the biophysical models. The input data of these models was also considered to be reliable given the reliable sources they came from (authorized public organizations) and the high spatial resolution. Although the multiple regression models of the disaster damages were developed by the national statistics (Table 1), there were some sources of uncertainty: basis of assumptions and limitation on spatial projection. Despite these uncertainties, we consider these results to be generally reliable because the result of each component of ecosystem services (DRR, carbon sequestration, water yield, and soil erosion) was estimated with the most comprehensive statistical data and the verified simulation models for the Republic of Korea (Lee et al., 2014; Kim et al., 2017). Furthermore, the estimate of each component had scientific significance in terms of spatial and temporal scales. Most studies, investigating these ecosystem services in the planted forests, were conducted at regional spatial scale and short (< 10 years) temporal scale (Schilling et al., 2008; Bangash et al., 2013; Yoo et al. 2013; Boithias et al., 2014; Shreve and Kelman, 2014; Song et al., 2015; Daigneault et al., 2016; Lotz et al., 2017). This study was conducted at the national scale for four decades. Accordingly, our estimates could provide a scientific basis for the long-term national strategy on environmental policies in other countries.

Table 2. The source and level of uncertainty in the biophysical assessment.

| Category | Level of uncertainty | Notes |
|---|---|---|
| Biophysical models (carbon sequestration, soil erosion, water yield) | Low | Verified models for the forests in the Republic of Korea (Lee et al., 2014; Kim et al., 2017) |
| Input data of the biophysical models | Low | Derived from the reliable statistical data; High quality of spatial resolution (1 $km^2$) |
| Multiple regression model (disaster risk reduction) | Medium | Derived from the reliable statistical data; Based on several assumptions Limitation on spatial projection |

**4.2. Uncertainty in the economic assessment**

There were some uncertainties in the economic assessment to the national forestation program in the Republic of Korea. In particular, the cost of the forestation might be overestimated because the annual budget of Korea Forest Service was used as the cost of the forestation. As the total annual budget was often provided without details, we could not exclude unrelated expenditure. In contrast, the benefits of the forestation program were underestimated because only four ecosystem services were included in this study due to the low data availability. In this study, DRR, carbon sequestration, water yield enhancement and soil erosion control were considered as the benefit of the forestation program while there were other potential benefits. These are components of provisioning and regulating services of forests, but other ecosystem functions in these categories of ecosystem services (e.g., raw materials, medicinal resources, air quality regulation and waste water treatment; TEEB, 2010) were not considered in this study due to the lack of data over the period. Habitat or supporting services (e.g., biodiversity and habitats for species) and cultural services (e.g., recreation, tourism) are also components of ecosystem services (TEEB, 2010). These cultural and habitat ecosystem services can account for anything between 18–62% of the total ecosystem services (de Groot et al., 2012; Kim et al., 2012). In particular, Kim et al. (2012) estimated that the annual benefit of these ecosystem services in the Republic of Korea to be up to 17 billion $ in 2008 (calculated with the PPP exchange rate). Not accounting for these services therefore means that our estimate might underestimate the total benefit of the forestation program. Although these benefits of the national forestation program seemed to be underestimated, the cost of the forestation was also overestimated. It implied the higher NPV and BCR of the forestation. Accordingly, the economic viability of the national forestation program is still ensured in the long-term regardless of uncertainty.

### 4.3. Implications

Our study suggests that an extensive forestation program such as the one in the Republic of Korea is very beneficial, showing high economic viability in the long-term. This high economic viability contributes to sustainable development. Recovery of forests conserves forest ecosystems and generates economic benefits to society. In particular, these economic benefits do not give burden to ecosystems, compared to some conventional development policies. The result of sensitivity analysis also showed that the indicators of economic viability were positive for a wide range of discount rates. It implied that the long-term economic viability of forestation would be ensured regardless of view taken on the appropriate rate. Our estimate especially provides a valuable reference on successful forestation program for developing countries, which encounter conflicts on land-use of forest land between utilization and conservation (Mutoko et al., 2015).

Furthermore, our approach of quantifying ecosystem services at the temporal and spatial scales can also support the implementation of environmental policy. Many countries underestimate economic values of forest ecosystems, not internalizing these values, owing to a lack of quantitative assessments. This phenomenon disregards the role of forests among land-use types. Providing the methodological framework and the high economic value of forest ecosystems can integrate forest ecosystem services into decision-making processes, contributing to implementation of optimal land-use policy.

Despite this high economic viability, just planting trees did not guarantee success of forestation. Illegal logging, slash-and-burn cultivation, and fuel wood demand, which are still encountered by many developing countries, also threatened the forestation program in the Republic of Korea at that time (NIFoS, 2010). To address these pressures, a successful forestation program needs to increase the welfare of villagers because poverty often leads to deforestation (Arevalo, 2016). In the case of the Republic of Korea, villagers also participated in managing nurseries, planting seedlings, and managing the planted area, supported from the governmental budget, during the forestation program in the Republic of Korea (NIFoS, 2010). In addition to strict regulation on illegal logging and slash-and-burn cultivation, the shift to other energy sources was subsidized to decrease in demand on forest wood resource (NIFoS, 2010). Lastly, after the forestation, consistent management is required to maintain the forested area. In fact, the budget for tending work of Korea Forest Service is one of the largest items recently in the Republic of Korea (from announcement by Korea Forest Service).To maximize the probability of success in forestation, other countries need to consider these secondary factors.

Meanwhile, the choice of plant species also had an ecological aspect. Fast-growing species (*Pinus* spp. and *Larix kaempferi*), surviving well in infertile environments, were mainly planted on the degraded lands during the national forestation program. The ecological characteristics of the species rather than their economic use improved the probability of success in the forestation program.

The case of the forestation program in the Republic of Korea also suggested that extensive and early investment is advantageous. The budget on the forestation in the Republic of Korea already had been invested before the 1970s. However, the monetary loss by disasters was still substantial and the forest carbon sequestration did not work effectively in spite of two main forestation program before 1970s. With the support of the above subsidiary factors, the extensive investment on the forestation started working and, as a result, the earlier investment started generating returns sooner than they otherwise would have. In addition it is important to remember that the benefits of ecosystem services by investment on forestation are consistently generated in the long-term. Accordingly, one must allow some time for these benefits to be realized.

## 5. Conclusion

The national forestation program in the Republic of Korea was economically viable in the long-term. DRR and carbon sequestration were especially enhanced by the forestation. This economic viability was guaranteed by the support from several subsidiary policy actions and early and extensive investment at that period. Our result, demonstrating the economic viability of extensive forestation program, can contribute to implementation of forestation for decision-makers in other countries.

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**Conflict of Interest:** The authors declare that they have no conflict of interest

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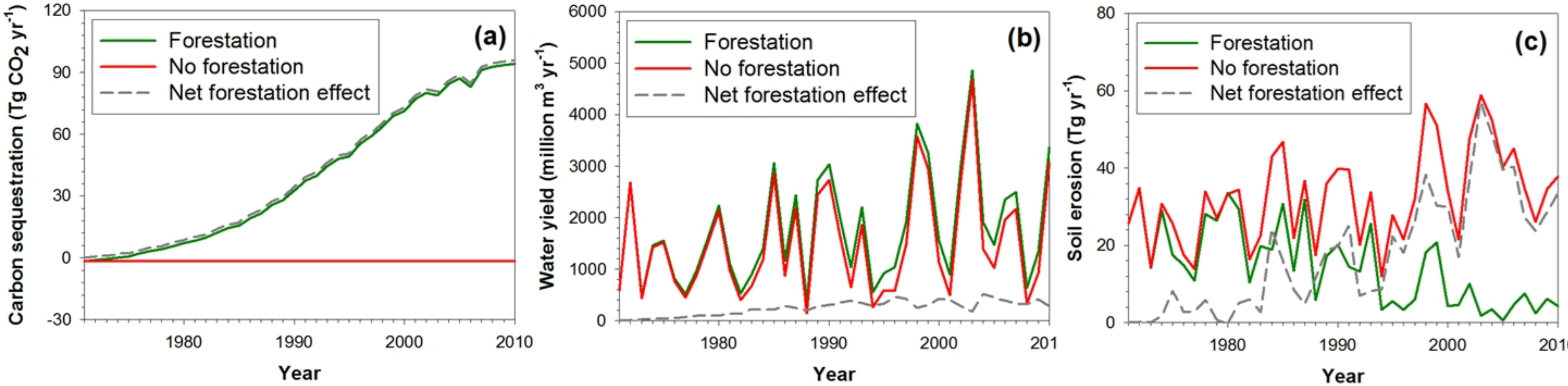
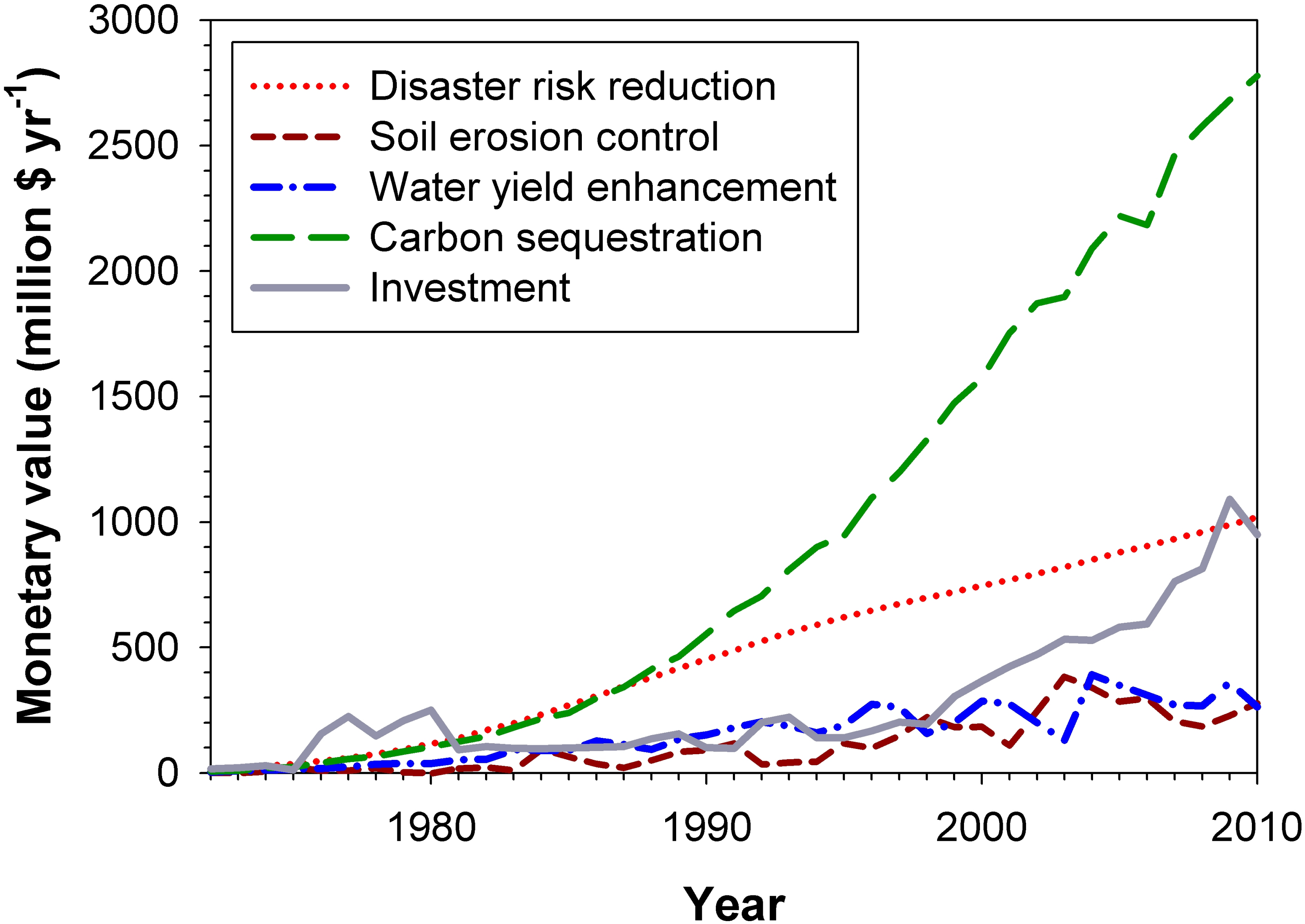
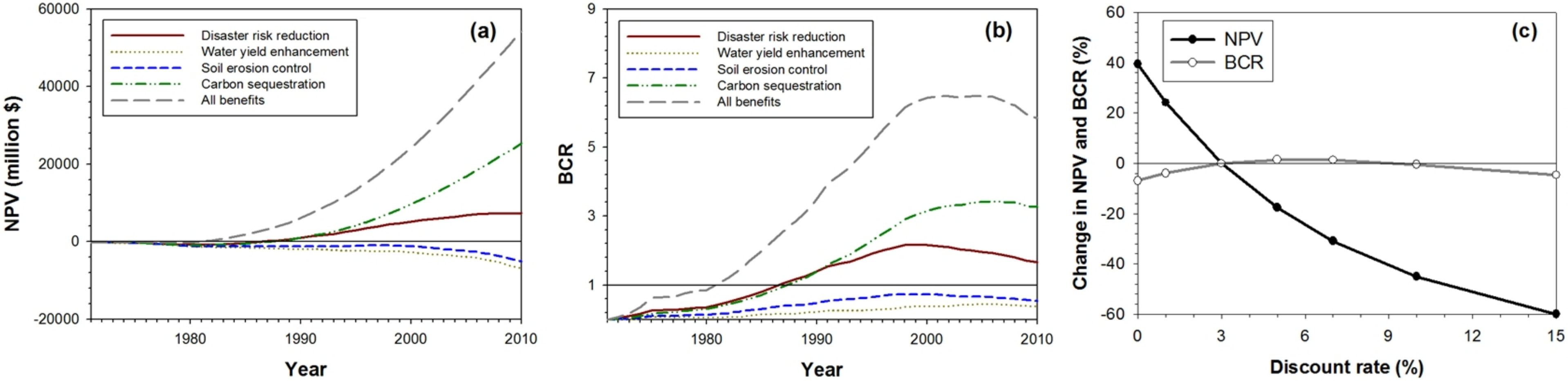


(a)
Forestation
No forestation
Net forestation effect
Carbon sequestration (Tg $CO_2$ yr$^{-1}$)
120
90
60
30
0
-30
1980
1990
2000
2010
Year
(b)
Forestation
No forestation
Net forestation effect
Water yield (million m$^3$ yr$^{-1}$)
6000
5000
4000
3000
2000
1000
0
1980
1990
2000
201
Year
(c)
Forestation
No forestation
Net forestation effect
Soil erosion (Tg yr$^{-1}$)
80
60
40
20
0
1980
1990
2000
2010
Year


3000
2500
2000
1500
1000
500
0
Monetary value (million $ yr-1)
1980
1990
2000
2010
Year
Disaster risk reduction
Soil erosion control
Water yield enhancement
Carbon sequestration
Investment



(a)
Disaster risk reduction
Water yield enhancement
Soil erosion control
Carbon sequestration
All benefits
NPV (million $)
60000
40000
20000
0
-20000
1980
1990
2000
2010
Year
(b)
Disaster risk reduction
Water yield enhancement
Soil erosion control
Carbon sequestration
All benefits
BCR
9
7
5
3
1
1980
1990
2000
2010
Year
(c)
NPV
BCR
Change in NPV and BCR (%)
60
40
20
0
-20
-40
-60
0
3
6
9
12
15
Discount rate (%)

Table 1. The multiple regression models of monetary loss by disasters. Monetary loss by disasters (million \$ $yr^{-1}$) = a × stocked forest area (1,000 ha) + b × mean annual precipitation (mm $yr^{-1}$). The stocked forest area is defined as forest area, which actually contains stocking volume (Kim et al., 2017).

| **Disasters** | **Coefficient** | | $r^2$ |
|---|---|---|---|
| | **a** | **b** | |
| Landslide | - | 0.04*** | 0.43 |
| Flooding | -0.21* | 1.88*** | 0.64 |
| Forest fire | 0.002** | - | 0.13 |

*: $P < 0.10$, **: $P < 0.05$, ***: $P < 0.01$.

Table 2. The source and level of uncertainty in the biophysical assessment.

| Category | Level of uncertainty | Notes |
|---|---|---|
| Biophysical models (carbon sequestration, soil erosion, water yield) | Low | Verified models for the forests in the Republic of Korea (Lee et al., 2014; Kim et al., 2017) |
| Input data of the biophysical models | Low | Derived from the reliable statistical data; High quality of spatial resolution (1 $km^2$) |
| Multiple regression model (disaster risk reduction) | Medium | Derived from the reliable statistical data; Based on several assumptions Limitation on spatial projection |