Responses to Referee 2

We greatly appreciate your constructive comments and suggestions. We revised the manuscript following your recommendations. Please refer to the responses below. The revised words, phrases, and sentences are in red color.

[For Major points]

Comment 1: The one major point appears to be a confusion in terminology: the authors report different values for Net Biome Production (NBP) and forest sinks. NBP is a measure of the net carbon balance of forests, i.e. as the authors state NEP minus losses from disturbances (and leaching losses which are often not quantified). Therefore where NBP is positive it should be the same value as the "sink". It could be that the authors are using the term NBP to refer to the flux density (g C m-2 yr-1) and the term sink for the country-level summary of NBP, but if that is what they did it needs to be explained more clearly. However, I would advise to follow the terminology defined in Chapin et al. 2006 and not differentiate between NPB and forest sink (or source). For example on page 5024 line 19, the authors state that "Compared to forests in other countries and global forests, the annual C sink rate of South Korean forests was much lower, but the NBP was much higher." This statement is confusing. Is the low "sink" here because Korea's forest area is small compared to that of other countries?

Response: We thank you for recommending Chapin et al. (2006). First, we defined net biome production (NBP) as an average of net ecosystem carbon balance (NECB) over space and time (Chapin et al., 2006). In addition, we defined annual C balance as the annual change in C stocks in the entire South Korean forest ecosystem to emphasize its difference from the NBP. Considering these terminologies, we revised some sentences throughout the manuscript and also provided definitions for annual C balance and NBP in the Materials and methods section as follows:

1) Page 5024 Lines 2–20 (Abstract)

"Forests play an important role in the global carbon (C) cycle, and the South Korean forests also contribute to this global C cycle. While the South Korean forest ecosystem was almost completely destroyed by exploitation and the Korean War, it has successfully recovered because of the national-scale reforestation programs since 1973. There have been several studies on the estimation of C stocks and balances in the South Korean forests over the past decades. However, retrospective long-term studies on biomass and dead organic matter (DOM) C and the validation of DOM C are insufficient to date. Accordingly, we estimated the C stocks and their changes in both biomass and DOM C during 1954–2012 by using a process-based model, the Korean Forest Soil Carbon model, and the 5th Korean National Forest Inventory (NFI) report. Validation processes were also conducted based on the 5th Korean NFI and statistical data. Simulation results showed that the biomass C stocks increased from 36.4 to 440.4 Tg C at a rate of 7.0 Tg C yr^{-1} during 1954–2012. The DOM C stocks increased from 386.0 to 463.1 Tg C at a rate of 1.3 Tg C yr^{-1} in the same period. The estimates of biomass and DOM C stocks agreed well with observed C stock data. The annual net biome production (NBP) during 1954–2012 was 141.3 g C m^{-2} yr^{-1}, which increased from -8.8 to 436.6 g C m^{-2} yr^{-1} in 1955 and 2012, respectively. Because of the small forested area, South Korean forests had a comparatively lower contribution to the annual C sequestration by global forests. In contrast, because of the extensive reforestation programs, the NBP of South Korean forests was much higher than those of other countries."

2) Page 5026 Lines 4–12 (Introduction)

"The primary objective of this study was to estimate C stocks and their changes in South Korean forests, including biomass and DOM during the post-war period (1954–2012), using the Korean Forest Soil Carbon model (KFSC; Yi et al., 2013) and South Korean NFI as input data. The estimated biomass and DOM C stocks were validated by comparing with the observed data in the 5th Korean NFI and Statistical Yearbook of Forestry. To estimate the effect of reforestation programs, we provided the annual C balance and NBP of South Korean forests before and after the onset of the programs. Furthermore, we compared the annual C balance and NBP in South Korean forests with those in major countries and global forests."

3) Page 5030 Line 17 (Materials and methods)

"2.3.2 Calculation of forest C stocks and NBP" was changed to "2.3.2 Calculation of forest C stocks, annual C balance, and NBP".

4) Page 5030 Line 24–Page 5031 Line 5 (Materials and methods)

"The annual C balance and NBP were calculated to estimate the change in C stocks in South Korean forests. The annual C balance (Tg C yr^{-1}) was defined as the annual change in C stocks in the entire South Korean forest ecosystem. In contrast, the NBP (g C m^{-2} yr^{-1}) is generally defined as the net primary production minus the heterotrophic respiration and the disturbances (fire, harvest, pests, land-use change, and other disturbances), and represents an average of the net ecosystem C balance over space and time (Chapin et al., 2006). As harvest was assumed to be the only disturbance and land-use change was not considered in this study, this model could simulate the net change of C stocks in the forest biome. To calculate the NBP of South Korean forests during certain period, the change in C stocks in South Korean forests were divided by the total simulation area (5870300 ha) and the corresponding period (yr)."

5) Page 5035 Line 4 (Results and discussion)

"C budget and balance" was changed to "C stocks and their changes".

6) Page 5036 Lines 4– 5 (Results and discussion)

"Because of the small forested area, South Korean forests had a comparatively lower contribution to the total C sequestration by global forests. However, the NBP of South Korean forests was much higher than those of other countries."

Comment 2: It is also of interest to note that the NBP estimates reported by the authors (436.6 g C m-2 yr-1 in 2012) are an order of magnitude greater than any of the values cited in the literature (Table 3). This is not inconceivable, however, because of the very unusual situation of having large forest areas with high growth rates and very low disturbances. It would be useful if the authors could provide further support for these very high estimates. For example, what are the corresponding estimates of NPP and Rh, and what are the corresponding stemwood volume growth rates obtained from KFRI yield tables. Note that 436 g C m-2 yr-1 if accumulated in stemwood only would require an AVERAGE growth rate of about 16 m3 ha-1 yr-1.

Response: To support the high NBP in South Korean forests, we provided the annual increment of C stocks in the biomass of *Pinus densiflora* and *Quercus variablilis*, which are the most abundant species among the needleleaf and broadleaf species, respectively. As about two-thirds of South

Korean forests are less than 40 years old (Korea Forest Service, 2013), we used the incremental rates at 20, 25, 30, 35, and 40 years, based on yield tables and BCFs (Biomass Conversion Factors in this study). In *P. densiflora*, the annual increment of C stock in biomass at 20, 25, 30, 35, and 40 years were 144.0, 401.4, 313.3, 226.4, and 160.4 g C m^{-2} yr^{-1}, respectively. In *Q. variabilis*, the rates in biomass at 20, 25, 30, 35, and 40 years were 588.3, 450.5, 330.3, 239.8, and 174.5 g C m^{-2} yr^{-1}, respectively. As these rates were calculated from the net biomass C change, the dead organic matter C input from the biomass was not considered. Considering that the incremental rates of C stocks in biomass are also derived from dead organic matter C input from biomass, these values explain the high NBP of South Korean forests. Furthermore, an empirical study conducted in the mature South Korean forest also suggested high rate of C sequestration (418 g C m^{-2} yr^{-1}; Noh et al., 2013). Finally, we added the following sentences right after Page 5034 Line 16 to support the high NBP of South Korean forests: "These high NBP values of South Korean forests were attributed to rapid increment of C stocks in biomass. As two-thirds of the South Korean forests are less than 40 years old (Korea Forest Service, 2013), the C stocks in biomass could rapidly increase. For example, the annual growth of biomass C stocks in the forests that are 20–40 years old ranged from 144.0 to 401.4 g C m^{-2} yr^{-1} for *P. densiflora* and from 174.5 to 588.3 g C m^{-2} yr^{-1} for *Q. variabilis*, based on the yield tables and BCFs. Considering that the dead organic matter C input from biomass contributed to these incremental rates, these values could explain the high NBP of South Korean forests. In addition, the empirical study conducted in the mature South Korean forest also indicated a high rate of C sequestration by forests (418 g C m^{-2} yr^{-1}; Noh et al., 2013)."

Comment 3: How much C is transferred annually by harvest? The authors only included harvest as a disturbance regime. Can you address in the discussion that the omission of other disturbances such as fires, insects, windstorms etc. can be ignored by providing a simple statement about the extent of such disturbances in Korea? There is no need to revise the analyses but the reader should be placed in the position to understand that these other disturbance types are not significant in area.

Response: To address your comment, we added the following sentence on Page 5031 Line 1 (in Materials and methods) before the "As harvest was assumed": "In South Korea, because of the extensive management of insect populations and negligible damage by forest fire (< 5% of annually harvested stemwood volume), the disturbances such as insects and fires could be ignored (Korea Forest Service, 1985, 1997, 2002, 2012)."

Comment 4: Lastly, the authors conclude that large-scale reforestation would contribute to mitigation of climate change – which is a well-known fact. However, few countries are in the situation Korea was in the 1950s with severely destroyed or degraded forests.

Response: As South Korean forests were extremely deforested, our results could not provide general implications to global forests. Accordingly, we revised the sentences on Page 5036 Lines 5–7 as follows: "The high NBP is a result of the implementation of extensive reforestation programs after the severe deforestation; thus, extensive reforestation activities after severe deforestation events would contribute to C sequestration for global climate change mitigation."

[For Minor points]

Comment 1: P 5024, L8 “a retrospective study…is still insufficient” – replace insufficient with “lacking”.
Response: We corrected it.

Comment 2: P 5024, L26 – the Kyoto Protocol did not “establish the function of forest as sink” but instead provided incentives to manage, report and account for the carbon balance of forests as sink or sources.
Response: We revised the sentence as follows: “The Kyoto Protocol encouraged the promotion of sustainable forest management practices and the contribution of forests to global C sequestration has been recognized (IPCC, 2003; UNFCCC, 1997).”

Comment 3: 5025, L11– not necessarily taking into DOM C – missing word “taking into ACCOUNT DOM C...”
Response: We corrected it.

Comment 4: P 5025, L16 – dynamics…has varied – should be “have varied”.
Response: We corrected it.

Comment 5: P 5025, L28 – determine the net C change IN BIOMASS – add “in biomass” for clarification.
Response: We added it.

Comment 6: P 5026 L23 – here or elsewhere you need to explain the relationship between the sampling points and the total forest area. How did you scale up from the sample points to the entire forest?
Response: Considering your comment, we revised some sentences in Section 2.1 as follows: “We used the 5th South Korean NFI data to prepare input data for the KFSC model and to validate the estimated DOM C stocks. The latest 5th NFI applied systematic cluster sampling for surveys at intervals of 4 km along the longitude and latitude (1 or 2 km for small forested areas), and obtained data from approximately 4000 plots during 2006–2010 (Korea Forest Research Institute, 2011). It provides information about forest type, species composition, diameter at breast height (DBH), age-class, stand density, topographical factors, observed C stocks of pools, and other data of each sampling plot. Each simulation unit represents a forest grid cell of 1 km × 1 km (43 cells), 2 km × 2 km (241 cells), or 4 km × 4 km (3606 cells). To upscale the plot-level data to the forest grid cells, the plot-level data were extrapolated and averaged to each forest grid cell. As denuded and bamboo forests were excluded in the simulation, 3890 cells (5870300 ha) were selected from the entire South Korean forests.”. Because the scaling up the forest grid cells to the entire South Korean forests was explained in section 2.3.2, we did not explain the process in this part.

Comment 7: P 5027 L11 – in the first part of this paragraph you introduced the concept of five dead organic matter (DOM) compartments, but here you state that biomass becomes input to soils – should this not become input to DOM pools.
Response: We substituted the word "soils" by "primary dead organic matter pools".

Comment 8: P 5028, L14 – This equation is unclear, where is the = sign?
Response: We clarified the equation as follows: "Fine roots / Foliage = 0.0016 × Stand age + 0.1012 (r^2 = 0.67)"

Comment 9: P 5028, L17 – If you emphasize elsewhere that the relationships between biomass pools change with stand age, why do use this static relationship for hardwood fine:coarse root ratios?
Response: Although the portion of fine roots to total root biomass may vary with stand age (Li et al., 2003), we used the static ratio of fine roots to coarse roots provided by Millikins and Bledsoe (1999) because the growth of fine roots has been poorly studied in South Korea. Millikins and Bledsoe (1999) provided this ratio for *Quercus douglasii*, a species from the same genus in our study of the South Korean forests. To define this limitation, we revised the sentence on Page 5028 Lines 16–17 as follows: "Since the growth function of fine roots in South Korean forests was unavailable, the static ratio of fine roots to coarse roots (11:89; Millikin and Bledsoe, 1999) was used to estimate C stocks of fine roots for broadleaf species."

Comment 10: P 5029, L26 – How many grid cells are there? How did you scale to the entire Korean forests?
Response: We added "3890" in front of "forest grid cells" to indicate the number of grid cells. As the method for scaling up the forest grid cells (simulation unit) to the entire Korean forests was explained in Section 2.3.2, an additional explanation of the method in this section seemed unnecessary.

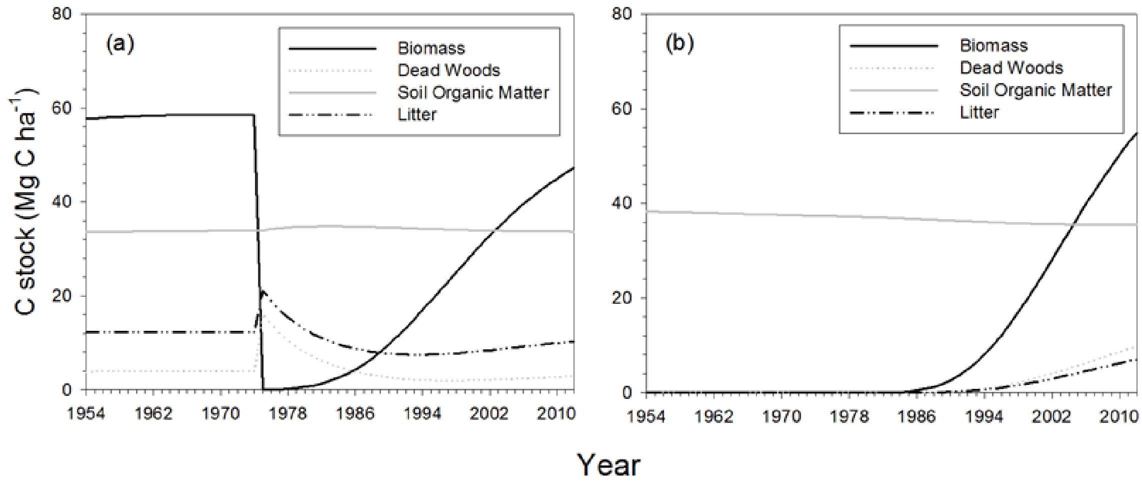
Comment 11: P 5031 L2 – Can you please clarify whether harvest includes partial cutting (thinning) or only final clearcut logging? What is the time series of assumed harvest rates?
Response: The harvest in the model includes only final clear-cut logging, and the harvest interval is 80 years. We substituted the word "harvest" on Page 5031 Line 2 with "80-year-interval clear-cut".

Comment 12: P 5032 L20 – Are these BEFs used by Choi and Chang (2004) species specific?
Response: They are forest type-specific BEFs. We emphasized that they are the forest type-specific BEFs and BCFs in the KFSC model are species-specific as follows: "We estimated the biomass C stocks with species-specific growth functions and BCFs. In contrast, Li et al. (2010) and Choi and Chang (2004) estimated the biomass C stocks by multiplying stemwood volume with forest type-specific (coniferous, deciduous, and mixed) and constant biomass expansion factors (BEFs)."

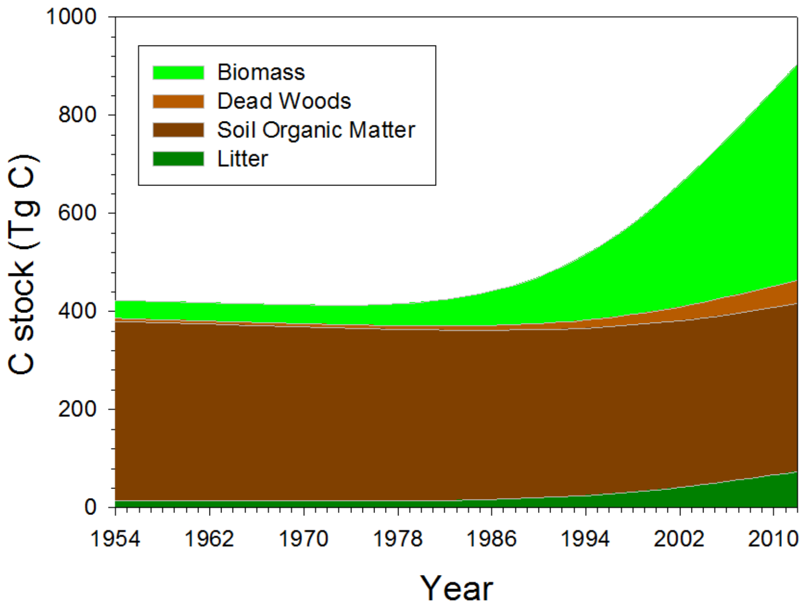
Comment 13: P 5044 Table 3 – please correct the units in Table 3 for NBP – these should be g C m-2 yr-1. Also clarify your distinction between sink and NBP as stated above.
<u>Response</u>: We corrected it.

Comment 14: P 5047, Fig 1 – caption – "The carbon pools consist" (not consists).
<u>Response</u>: We corrected it.

Comment 15: P 5048 Fig 2a – the diagram shows a very large drop in biomass associated with harvest, but a very small corresponding increase in DOM pools. This increase is insufficient to account for the biomass of coarse roots and stumps which are left behind after logging even if all other harvest slash were removed from the site (which is unlikely). Is there another C pool not shown in that figure which would account for the remaining C on site?
<u>Response</u>: In the earlier version of Figure 2, the dead roots and coarse woody debris were excluded. We revised the figure based on the IPCC categories (biomass, dead woods, soil organic matter, and litter) as follows:



Comment 16: P 5049, Fig 3 – it would be helpful to also show the breakdown of DOM pools into the IPCC categories.
<u>Response</u>: We followed the IPCC categories and revised the figure to provide the change in C stocks of biomass, dead woods, soil organic matter, and litter as follows:



Reference for the response

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Added references to the manuscript

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