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Spatial assessment of ecosystem functions and services for air purification of forests in South Korea

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ABSTRACT

Ecosystem functions can be understood as the quantified amount of an ecosystem's role in a natural process, while ecosystem services are the requantification of the ecosystem functions by factoring in environmental conditions and human needs based on social perspectives. In this study, differences between ecosystem functions and services were presented in terms of air purification of a forest ecosystem. Forest volume growth was employed to quantify the pollutant absorption capacity of a forest and was indicated by the natural functions (NF) for air purification by a forest ecosystem. Forest ecosystem services can be requantified from the forest functions by adding the air pollutant and population densities. Air pollutant density was applied to the assessment of the environmental services (ES) of forest ecosystems. Furthermore, the environmental social services (ESS) of forest ecosystems were assessed by including population density considerations. We simulated differences in NF, ES, and ESS in relation to pollutant and population density; while NF was spatially quantified without a close relationship to air pollutant and population density, ES and ESS reacted to environmental and social condition more sensitively. These results imply that the ecosystem services of forest resources for air purification are high where the pollutant and population densities are high, while the ecosystem functions of forest resources for air purification depend solely on forest conditions and not on the density changes of air pollutants and population. This study suggests that the differences in NF, ES, and ESS are important factors to be understood and considered in the decision-making process for ecosystem services. When considering human needs and surrounding environmental conditions, the results suggest that decision makers should utilize the ES and ESS concepts, which reflect both population and pollutant density along with additional human-related factors.

1. Introduction

The concept of ecosystem services is now broadly applied in complex decision making; it includes various methods and standards, yet the optimal method of assessment is still a work in progress (Collins et al., 2010; Costanza et al., 1998, 2006; Daily, 1997; de Groot et al., 2002). In contribution toward such assessments, many attempts have been made to investigate specific functions and services of ecosystems. A set of standards for classifying and assessing ecosystem functions and services in a region-specific approach has been suggested (Costanza et al., 1998; de Groot et al., 2010; Maes et al., 2013; Ruckelshaus et al., 2015; TEEB, 2010).

However, ecosystem services have not been clearly distinguished from ecosystem functions (Carpenter et al., 2009; Chung and Kang, 2013; Collins et al., 2010). An ecosystem function usually refers to the combination of processes and structures of an ecosystem, and it can represent the potential capacity to deliver ecosystem services. Accordingly, ecosystem functions are occasionally referred to as "functions of nature" (Costanza et al., 1998; de Groot et al., 2010; Maes et al., 2011). Unlike ecosystem functions, ecosystem services can be defined human benefits from obtaining goods and services from the ecosystem. Therefore, ecosystem services reflect human demand and are driven by perception of ecosystem service classification and economic evaluation

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(Ahn, 2013; Costanza et al., 1998; de Groot et al., 2010; Rosenthal et al., 2015; Ruckelshaus et al., 2015). Ecosystem services imply access and demand by humans, so they are used to assess ecosystem goods and benefits through methods of economic valuation. In the absence of human beneficiaries, ecosystem functions are not ecosystem services; in other words, ecosystem services reflect both environmental conditions and human needs (Costanza et al., 1998; de Groot et al., 2010; Fisher et al., 2009; Maes et al., 2011). Although there have been clear definitions of ecosystem functions and services, there is still confusion in the assessment of ecosystem functions and services (Collins et al., 2010). That is, in previous studies, unit prices have been simply multiplied by certain units of quantified ecosystem functions to translate the benefits of ecosystem functions into economic value (Chung and Kang, 2013; de Groot et al., 2002). Therefore, presently, what is referred to as ecosystem services are basically ecosystem functions expressed in units of currency (Rosenthal et al., 2015; Ruckelshaus et al., 2015). Information about ecosystem functions and services have also been visualized through mapping to help aid in management decisions (Burkhard et al., 2012; Costanza et al., 1998; Daily, 1997; de Groot et al., 2002; Millennium Ecosystem Assessment, 2005; TEEB, 2010; UK National Ecosystem Assessment, 2011). However, the mapping and spatial modeling of ecosystem functions and services are still limited by model selection, data preparation, scaling decisions, and validation. These limitations in the spatial modeling of environmental conditions and human needs are caused the dynamics in social activities and the response of both ecosystem functions and services (Burkhard et al., 2012; Crossman et al., 2013; Jeon et al., 2013; Leh et al., 2013; Schägner et al., 2013). Therefore, the spatial assessment of ecosystem services considering environmental conditions and social needs as well as natural functions is vital for further realistic environmental policy and decision making but still challenging process.

In this study, the differences between ecosystem functions and services were examined through the assessment of air purification (pollutant sequestration function), specifically, SO_2 and NO_2 sequestration, which is usually known as a regulating function and service of forests (Millennium Ecosystem Assessment, 2005; Ninan and Inoue, 2013; TEEB, 2010). Based on the methodologies of this assessment, this study determined the natural functions (NF) as the ecosystem functions and environmental services (ES) and environmental social services (ESS) as the ecosystem services. In addition, three sets of spatial maps of ecosystem functions and services were prepared for facilitating spatio-temporally adequate decision-making processes.

2. Materials and methods

2.1. Study area

The Republic of Korea (South Korea) was the main study area, with a specific focus on forest areas, which cover around 64% of the land area. Korean forests are approximately 38% coniferous, 47% broadleaf, 12% mixed forests, and 3% other types. The main age class was the 3–4 age class (21–40 years), and the overall volume per hectare was 126.73 m^3/ha (Figs. 1 and 2; Choi et al., 2014; Nam et al., 2015).

2.2. Methods

Trees and other vegetation in forests absorb air pollutants through their leaf surfaces and reduce pollutant dispersion; this process of absorption is linked with CO_2 sequestration by photosynthesis. Accordingly, air pollutant absorption can be considered as a NF of forest ecosystems. A high NF can imply a high level of ecosystem functions, but the NF of a forest ecosystem may not directly represent its ecosystem service. In other words, spatial NF assessment results can be directly interpreted to ecosystem services in some cases (Frélichová et al., 2014; Ninan and Inoue, 2013), however, some previous studies of ecosystem services used weighted economic values driven by humans (Alam et al., 2016; Burkhard et al., 2012). Thus, the lower level NF area with high economic value could have possibility to exceed more ecosystem service value than the high level NF area. Therefore, the ecosystem services of forest ecosystems should be assessed by considering environmental conditions and human needs.

The demand for good air quality increases when people are exposed to poor air quality caused by rising air pollutant emission; on the other hand, demand for good air quality decreases when

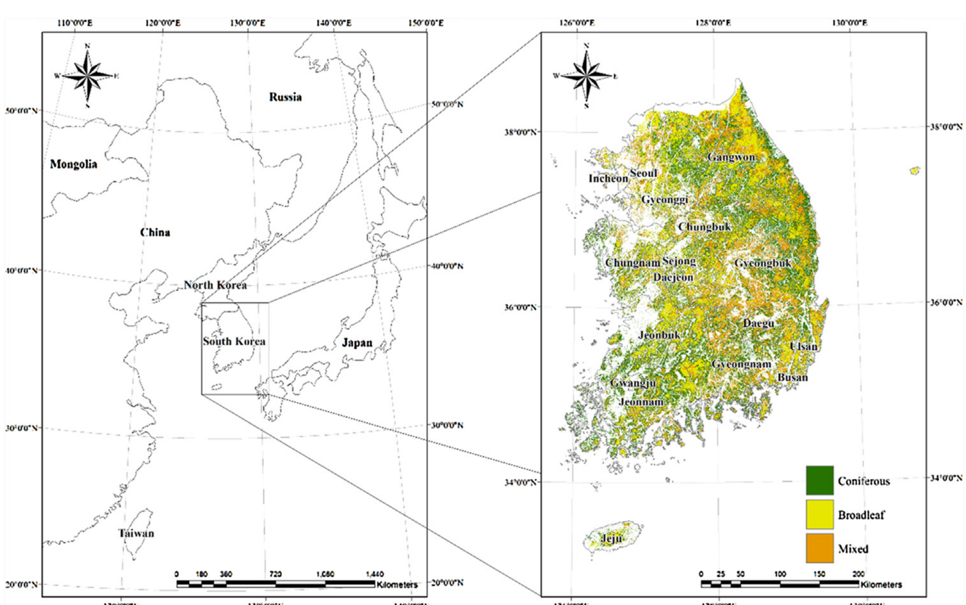


Fig. 1. Forest area in South Korea.

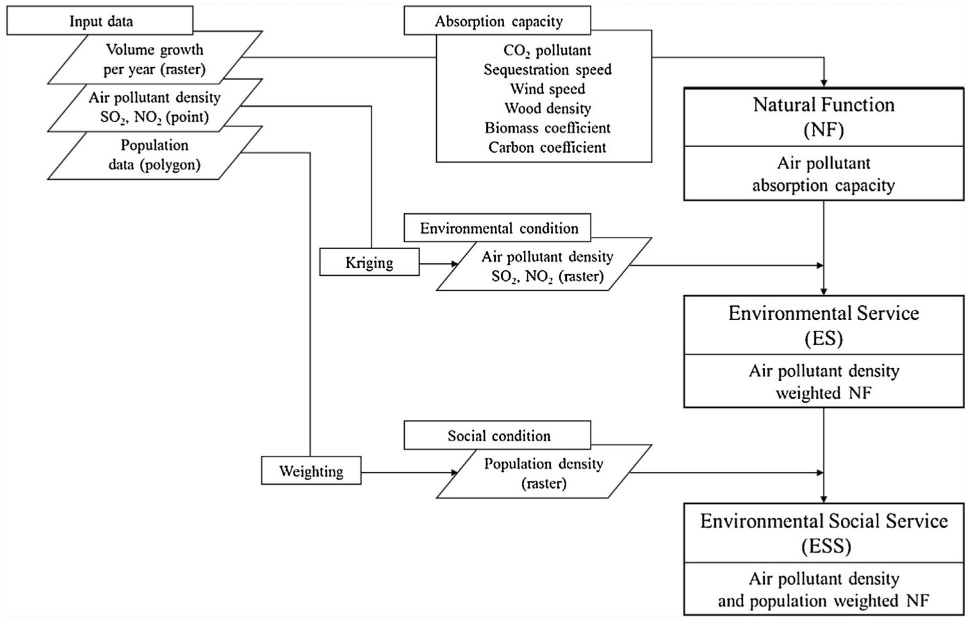


Fig. 2. Flow diagram for assessing natural functions (NF), environmental services (ES), and environmental social services (ESS).

there are low air pollutant emissions. The demand can be determined by environmental and social conditions (Vallero, 2014). Overall, the concepts are defined as follows:

Natural Functions (NF): Direct and potential functions from a specific ecosystem that can be connected with other specific ecosystem functions. In this study, the NF was the tree's capacity to absorb air pollutants.

Environmental Services (ES): Ecosystem services that consider environmental conditions. In this study, air pollutant density was employed for representing environmental conditions.

Environmental Social Services (ESS): Ecosystem services that are related to social conditions as well as environmental conditions. In this study, population was applied as a representative factor for explaining social conditions.

First, the NF of forests for absorption capacity of NO_2 and SO_2 was assessed. Second, the air pollutant density was employed as the environmental condition for assessing ES. Third, the population density was additionally employed as the social condition for assessing ESS (Bagstad et al., 2013; Guerry et al., 2012; Ramirez-Andreotta et al., 2014; Wilson and Hoehn, 2006) (Fig. 2).

The applied equations for NF, ES, and ESS were:

$$\text{NF} = \text{Amount of air pollutant sequestration} \tag{1}$$

$$\text{ES} = \text{NF} \times \text{Air pollutant density} \tag{2}$$

$$\text{ESS} = \text{NF} \times \text{Population weighted value} \tag{3}$$

In this study, NF assessment was conducted in accordance with former studies, following equations (4) through (7). The total flux tree sequestration of air pollutants (W_x) was calculated by the specific gas sequestration speed (XO_a), carbon dioxide sequestration speed (CO_a), and carbon dioxide sequestration amount (T_G). The equations are as follows:

$$W_x = \left(\frac{XO_a}{CO_a}\right) \times T_G \tag{4}$$

$$XO_a = AS_r \times DC \times PD_x \tag{5}$$

$$CO_a = AS_c \times WS \times PD_c \tag{6}$$

$$T_G = V_G \times WD \times BEF \times (1 + R) \times CF \times \frac{44}{12} \tag{7}$$

The SO_2 and NO_2 sequestration speed (XO_a) was determined by the gaseous pollutant density (PD_x) and its relative sequestration speed ratio when compared with the CO_2 sequestration speed (AS_r). Then, the density conversion coefficient (DC) was applied to match units between CO_2 and the specific gaseous pollutant. The CO_2 sequestration speed (CO_a) can be estimated through the tree sequestration speed of CO_2 (AS_c), wind speed (WS), and CO_2 density (PD_c). The tree CO_2 sequestration amount (T_G) was estimated through the volume growth per year (V_G), wood density (WD), biomass coefficient (BEF), root ratio (R), carbon coefficient (CF), and CO_2 coefficient ($\frac{44}{12}$). (Choi et al., 2012; Dong et al., 2015; Hill, 1971; Jim and Chen, 2008; Kim et al., 2010; Ninan and Inoue, 2013; Smith, 2012). This study applied the following weighted value for the population density.

$$\text{Weighted Value} = \frac{(R_{max} - R_{min})}{(V_{max} - V_{min})} \times (V - V_{max}) + R_{max} \tag{8}$$

The equation consists of weighting the population data, where V is the original population data value; V_{max} and V_{min} are the maximum and minimum values, respectively; and R_{max} and R_{min} are the maximum and minimum values, respectively, of the range set by the investigator. This study used the human population by administrative district as the weighted value and modified it to the range of 1–1.2. The minimum value was set to 1, since the population in each administrative district was greater than a single individual, also indicating that in each area.

2.3. Data preparation

To assess the NF, ES, and ESS, four data sets were prepared and adjusted spatially in South Korea. Other data were mainly coefficients or statistics from national statistics, reports from national research institutes, and previous studies (Tables 1 and 2).

Table 1
Data for assessing forest air purification.

Data Description	Data type	Source
Volume growth per year	Raster	Nam et al. (2015)
Gaseous pollutant density (SO_2, NO_2)	Point	KECO (2011)
Administrative district	Polygon	SGIS (2012)
Population data	Polygon	SGIS (2012)
Gaseous pollutant density (CO_2)	Number	CCIC (2011)
Sequestration speeds (CO_2, SO_2, NO_2)	Number	Hill (1971)
Wind speed	Number	KMA (2011)
Wood density	Number	Son et al. (2007)
Biomass coefficient	Number	Son et al. (2007)
Carbon coefficient	Number	Son et al. (2007)

For the volume growth per year, this study used spatial data which had been adjusted based on forest cover and volume change by the National Forest Inventory (NFI). It also considered the forest growth model simulation results according to future climate change and the forest practice area because NFI data produced each quinquennial cycles (Nam et al., 2015). Although the Korea Forest Service provides national forest statistics and forest type maps, the maps are not in raster format and do not reflect recent data from the latest NFI investigations. The spatial resolution of these data is 1 km × 1 km (Fig. 3).

The gaseous pollutant density was spatially analyzed from point data of >300 observation stations that gather atmospheric air pollutant density data (National Institute of Environmental Research, 2012) in ppm. To generate raster data of SO_2 and NO_2 from point data, this study selected kriging – a geostatistical method of interpolation (Fig. 3) based on semi-variograms that estimates unknown value points (Kim and Jun, 2014; Park and Kim, 2013).

3. Results

3.1. Spatial distribution of ecosystem function and service

The NF maps represented the functional capacity of forests for air pollutant absorption. Some areas such as Jeju Island and South western coastal area demonstrated a high growth rate due to the presence of young trees that possess a high NF for the forest ecosystem. The spatial patterns of the ecosystem services maps, including ES and ESS, generally followed spatial patterns of air pollutant density (Figs. 4 and 5). Both maps demonstrated that industrialized and urban areas such as Ulsan and Seoul produced high ecosystem services, while rural and mountain areas produced low ecosystem services even though they had the same pollutant absorption capacity via NF.

However, ES and ESS maps showed several differences. As population-based human factors were applied and weighted, the Jeonbuk and Gangwon areas showed different levels of ecosystem service production (Figs. 4 and 5). In addition, some pixels in urban areas showed higher or lower levels of ecosystem service production relative to the ES map.

Table 2
Amount of SO_2 and NO_2 sequestration (per unit area).

Studies	kg SO_2/ha	kg NO_2/ha	Research area
This study	8.60	16.80	Entire country
Kim et al. (2010)	5.97–11.48	10.72–21.24	Entire country
Jo et al. (2002)	17.10	43.90	Seoul
Choi et al. (2012)	3.4–34.0	9.2–80.8	Daegu

Among the three types of results, the ES map was the only option to compare with previous studies, because the lack of numerical and quantitative assessments in the study area. In addition, comparable studies were also limited when considering correspondence with NF, ES, and ESS concepts. As the ES results in this study, the total SO_2 sequestration amount of the all Korean forests in 2011 was 52,150 tons of SO_2, with an average of 8.6 kg SO_2/ha. In the case of NO_2, the total amount reached 93,254 tons of NO_2, with an average of 16.8 kg NO_2/ha.

In the former studies, quantified values were referred to as public functions, ecosystem functions, or ecosystem services. The results of this study were also compared to the conclusions from previous studies conducted in Korea. Being on a national-scale, the study results were only comparable to the statistical result (5.97–11.48 kg SO_2/ha, 10.72–21.24 kg NO_2/ha) of Kim et al. (2010). A comparison of data showed that the amounts of air pollutant sequestration in this

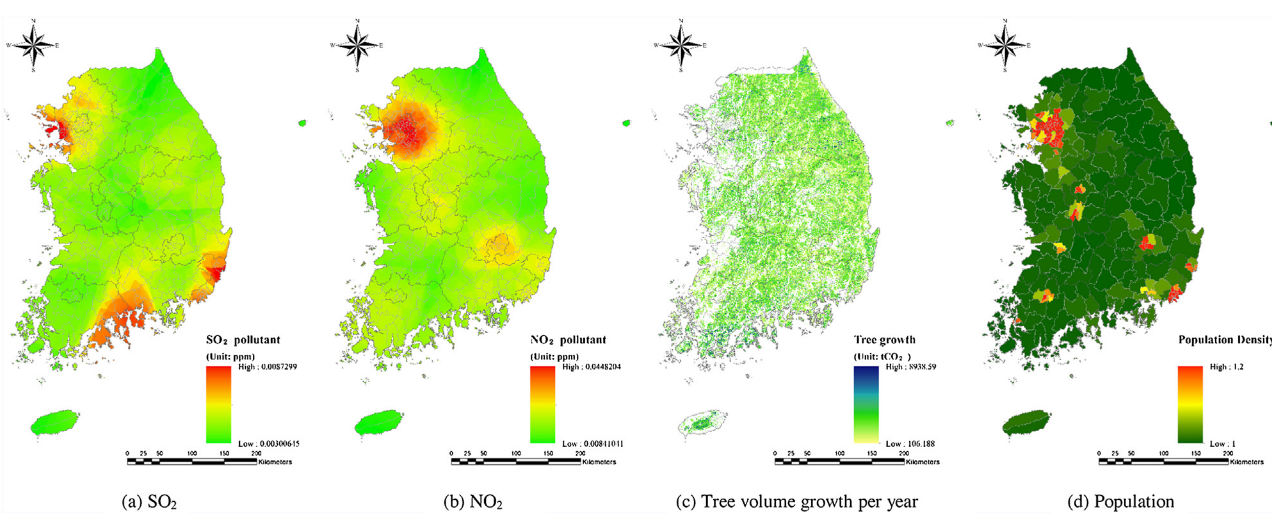


Fig. 3. Spatial data for SO_2 (a), NO_2 (b), tree volume growth per year (c), and population (d).

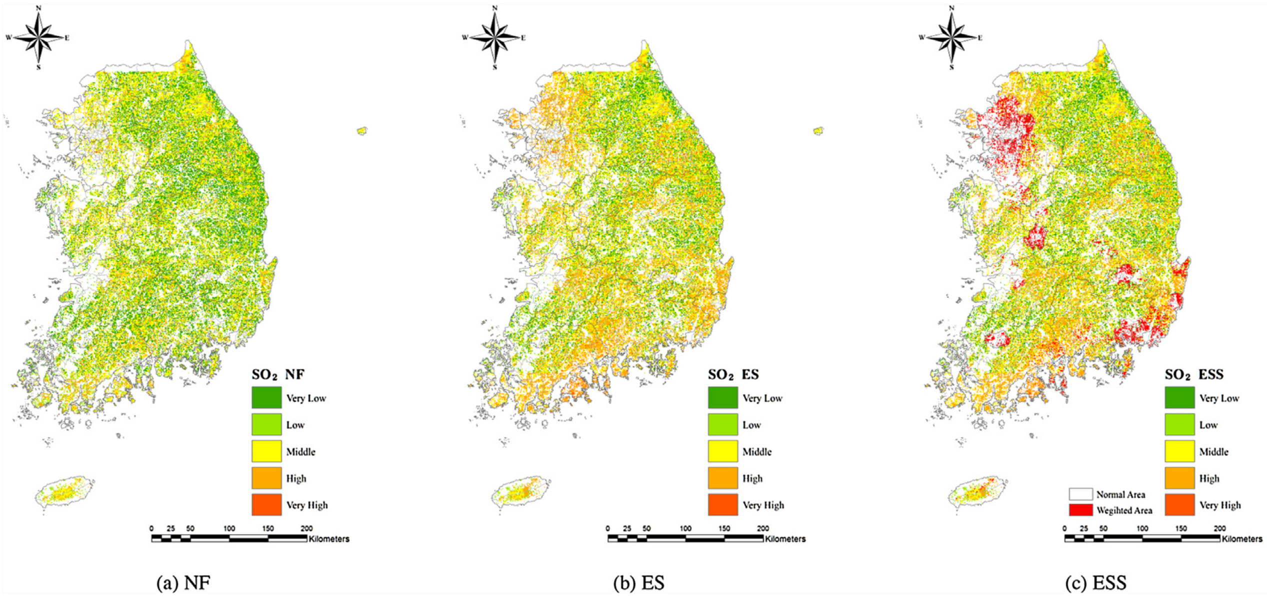


Fig. 4. Natural function (NF), environmental service (ES), and environmental social service (ESS) maps of SO_2 purification.

study corresponded to the range found in the former study, and so the overall estimates were deemed reasonable. However, at the city level, the former results appeared to be overestimated. Although results from Seoul (17.10 kg SO_2/ha, 43.90 kg NO_2/ha) and Daegu (3.4–34.0 kg SO_2/ha, 9.2–80.8 kg NO_2/ha) were higher than those at the national level, they reflected various regional characteristics that contributed to high air pollutant density; for example, both areas are urban, industrialized, and surrounded by mountains. However, results from the whole country were much lower than the results of the urban areas since the former included sizeable areas of lower air pollutant density.

3.2. Relationship of ecosystem function and service

Subsequently, the SO_2 and NO_2 results from the three maps (Figs. 4 and 5) were graphed to compare their rates of change of ES and ESS (Figs. 6 and 7). In the linear graph, the X axis represented the air pollutant density, while the Y axis represented the potential capacity of NF. In the case of the NF assessment, both the graphs of SO_2 and NO_2 displayed a horizontal curve (NF, black squares), while the ecosystem services from the ES (white dots) and ESS (grey dots) had positive slopes in both graphs (Figs. 6 and 7). Therefore, NF was not found to be related to changes in air pollutant density at the

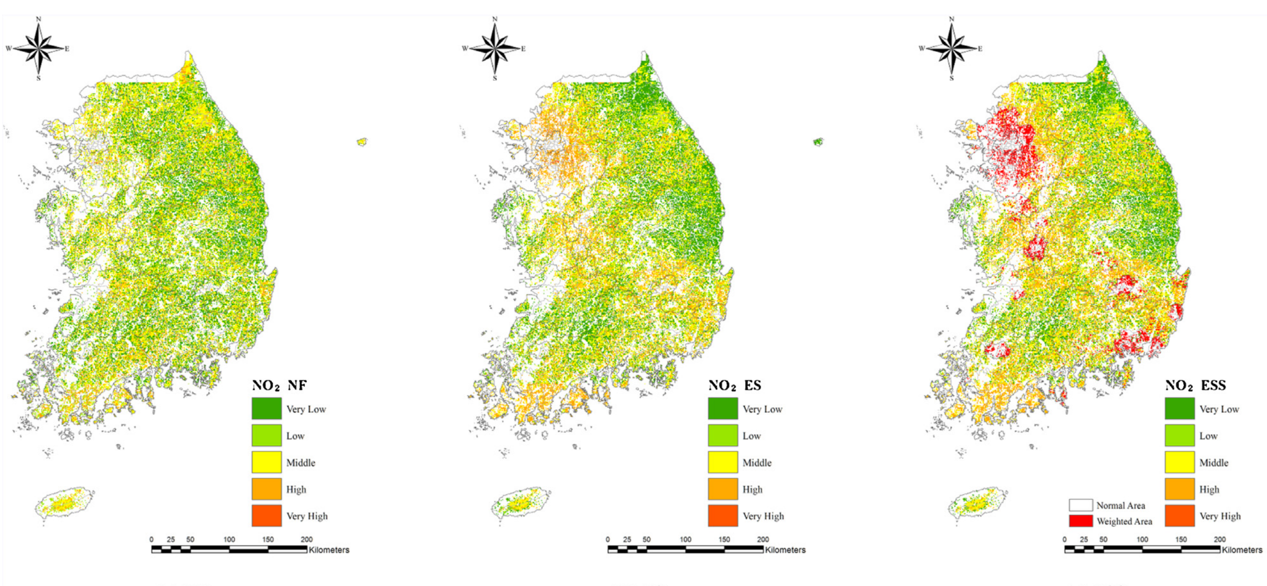


Fig. 5. Natural function (NF), environmental service (ES), and environmental social service (ESS) maps of NO_2 purification.

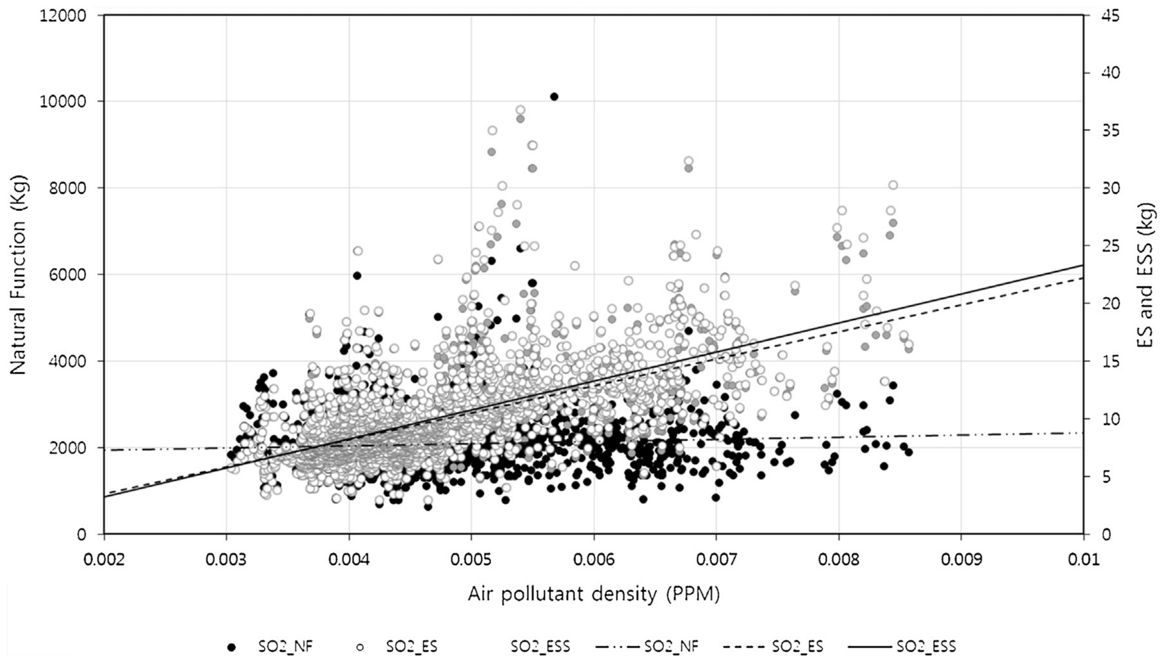


Fig. 6. Differences between the natural function (NF), environmental services (ES), and environmental social services (ESS) in SO_2 purification.

pixel scale (1 km × 1 km); however, ES and ESS maps did react to the changes in air pollutant density.

Figs. 8 and 9 show 3-dimensional graphs for describing the effect of pollutant density and NF on ES. NF had a positive relationship with ES, but when there were higher pollutant and population densities, the role of NF in ecosystem services was higher. We can identify the effect from the steep slope of NF at higher densities (Fig. 8).

4. Discussion

This study conceptually split previous assessment processes to analyze the differences between ecosystem functions and services. In addition, air pollution was set as the environmental condition to indicate the human influence which made actual quantification among NF capacity, although air pollutant density has already been applied in former studies and functional processes. Therefore, NF,

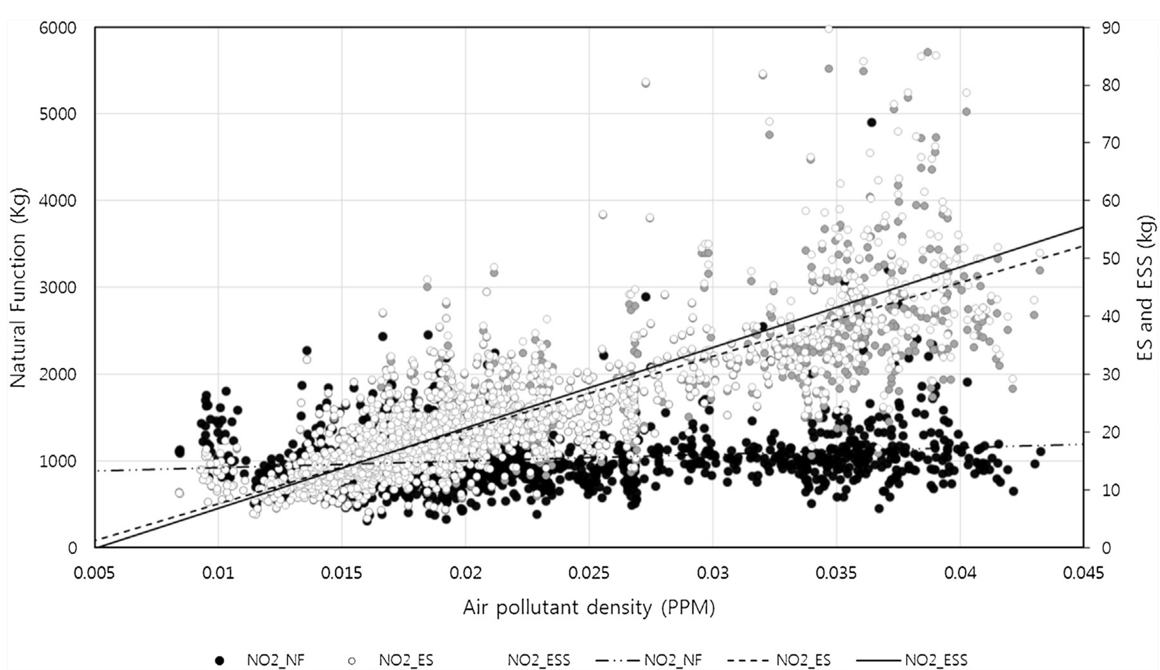
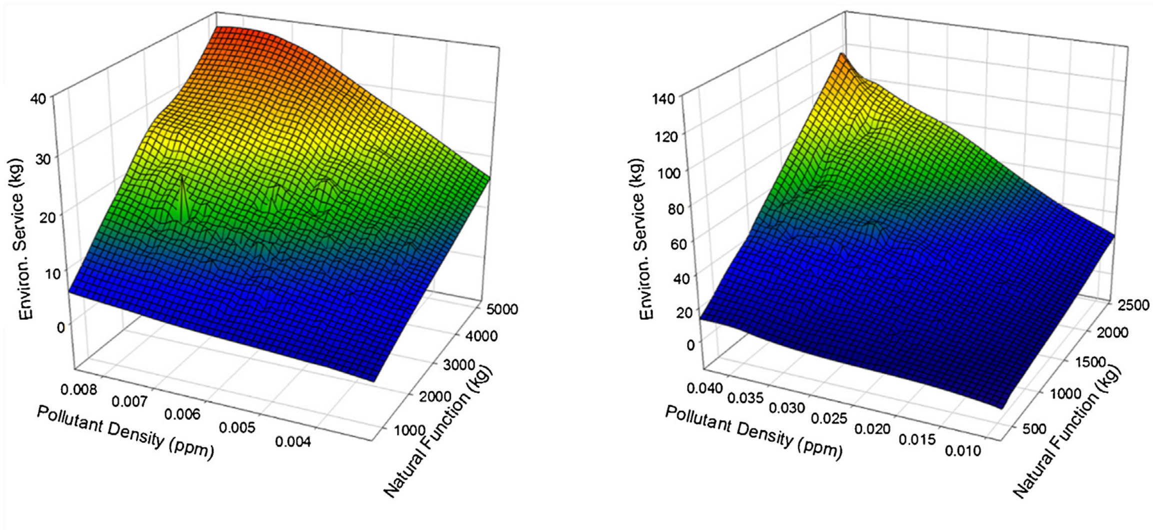


Fig. 7. Differences between the natural function (NF), environmental services (ES), and environmental social services (ESS) in NO_2 purification.



(a) SO_2 (b) NO_2

Fig. 8. Relationship among pollutant density, natural function (NF), and environmental services (ES).

ES, and ESS were conceptually divided for increased specificity. The resulting three assessment maps showed that the human needs for ecosystem services are various and diverse according to environmental and social conditions.

Limitations of this study come from the data availability in ESS assessment. These are similar to the problems of ecosystem mapping and spatial analysis processing, primary data for modeling, and functional assessment processing that also require further development (Burkhard et al., 2012; Schägner et al., 2013). To assess human needs for ESS, field surveys were usually needed to quantify the actual benefit; this in-field effort would take into account human perspectives and integrate them with spatial resolution results from NF modeling. In small-scale regions, this survey and monitor approach is practically realizable; however, at a large scale, such a measure would currently require a lot of time and resources (Burkhard et al., 2012; Crossman et al., 2013; Fisher et al., 2009). In this study, weighted value of population density were applied for assessing ESS through weighted values. Therefore, we could save time and resources to obtain data, when users need to assess specific results of ESS. However, at same time, we still faced the challenges to develop appropriate methods for spatial modeling of human needs.

Nevertheless, the separation of NF, ES, and ESS assessment processes in a single model is an important consideration. As mentioned previously, policy makers who focus on the benefits of ESS due to extreme human demands can make unreasonable decisions in terms of preserving the environment and enhancing NF or ES. Therefore, policy makers should have NF, ES and ESS information that indicate trade-offs between them in order to pursue a balanced development and conservation policy at a greater than regional level (Pittock et al., 2012). Thus, the analysis of spatial models and determination of the key data related to demands through accurate mapping remain as important future work (Bagstad et al., 2013; Crossman et al., 2013; Jeon et al., 2013).

Additionally, we need to develop more spatial ES and ESS models based on NF. The CO_2 sequestration amount which had was spatially constructed was used NF of air purification in this study, however it also has possibility to indicate climate change regulation or provisioning of timber. With this kind of NF, each ES and ESS could be differently assessed. Therefore, the aim of NF, ES and ESS assessment would not be limited to resolving confusion between ecosystem functions and services but also improve understanding of economic values, human demand scale, and future assessment modeling.

5. Conclusion

Ecosystem services are becoming important in solving environmental conflicts based on the concept of natural capital. These economic perspectives affect their valuation through reflecting human needs; thus, many former studies have suggested conceptual flows between ecosystem functions and services. In these studies, ecosystem functions referred to processes and structures of the ecosystem, whereas ecosystem services referred to the amount of human benefit in terms of demand for goods or services obtained from the ecosystem.

To provide a more balanced perspective, this study addressed the differences between ecosystem functions and services by focusing on air purification by forest ecosystems. The study found that the value of NF was spatially, randomly distributed according to the forest condition, while the values of ES and ESS were higher in urban areas where industrial and human activities occur. The ES and ESS also increased with increasing density of air pollution, while the NF was not dependent on the density. At higher pollutant densities, NF has a more positive effect on ES and ESS. With an understanding of the differences among the NF, ES, and ESS concepts, decision makers could be equipped with more efficient and effective tools for the management of ecosystem services.

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References

Ahn, S., 2013. Definition and classification of ecosystem services for decision making. J. Environ. Policy 12, 3–16.
Alam, M., Dupras, J., Messier, C., 2016. A framework towards a composite indicator for urban ecosystem services. Ecol. Indic. 60, 38–44.
Bagstad, K.J., Semmens, D.J., Waage, S., Winthrop, R., 2013. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosyst. Serv. 5, 27–39.
Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply demand and budgets. Ecol. Indic. 21, 17–29.

CCIC (Climate Change Information Center), 2011. URL: https://www.climate.go.kr:8005/index.html (accessed 07.05.15.).
Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R.S., Díaz, S., Dietz, T., Duraiappah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., 2009. Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. Proc. Natl. Acad. Sci. 106 (5), 1305–1312.
Choi, C.H., Lee, W.S., Jung, S.G., 2012. A quantitative analysis of air purification effectiveness on urban forest considering the spatial distribution of pollutant concentration. J. Korean Assoc. Geogr. Inf. Stud. 15, 71–85.
Choi, K., Kim, M., Lee, W.K., Gang, H.U., Chung, D.J., Ko, E.J., Yun, B.H., Kim, C.H., 2014. Estimating radial growth response of major tree species using climatic and topographic condition in South Korea. Clim. Change Res. 5, 127–137.
Chung, M.G., Kang, H., 2013. A review of ecosystem service studies: concept, approach and future work in Korea. J. Ecol. Environ. 36, 1–9.
Collins, S.L., Carpenter, S.R., Swinton, S.M., Orenstein, D.E., Childers, D.L., Gragson, T. L., Grimm, N.B., Grove, J.M., Harlan, S.L., Kaye, J.P., Knapp, A.K., Kokinas, G.P., Magnuson, J.J., McDowell, W.H., Melack, J.M., Ogden, L.A., Robertson, G.P., Smith, M.D., Whitmer, A.C., 2010. An integrated conceptual framework for long-term social-ecological research. Front. Ecol. Environ. 9, 351–357.
Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., Van Den Belt, M., 1998. The value of the world's ecosystem services and natural capital. Ecol. Econ. 1, 3–15.
Costanza, R., Wilson, M.A., Troy, A., Voinov, A., Liu, S., D'Agostino, J., 2006. The Value of New Jersey's Ecosystem Services and Natural Capital. New Jersey Department of Environmental Protection.
de Groot, R.S., Wilson, M.A., Boumans, R.M., 2002. A typology for the classification, description and valuation of ecosystem functions goods and services. Ecol. Econ. 41, 393–408.
de Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol. Complexity 7, 260–272.
Crossman, N.D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Drakou, E. G., Martin-Lopez, B., McPhearson, T., Boyanova, K., Alkemade, R., Egoh, B., Dunbar, M.B., Maes, J., 2013. A blueprint for mapping and modelling ecosystem services. Ecosyst. Serv. 4, 4–14.
Daily, G., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D.C.
Dong, H., Dai, H., Dong, L., Fujita, T., Geng, Y., Klimont, Z., Inoue, T., Bunya, S., Fujii, M., Masui, T., 2015. Pursuing air pollutant co-benefits of CO_2 mitigation in China: a provincial leveled analysis. Appl. Energy 144, 165–174.
Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. 68, 643–653.
Frélichová, J., Vačkář, D., Pártl, A., Loučková, B., Harmáčková, Z.V., Lorencová, E., 2014. Integrated assessment of ecosystem services in the Czech Republic. Ecosyst. Serv. 8, 110–117.
Guerry, A., Ruckelshaus, M., Arkema, K., Bernhardt, J., Guannel, G., Kim, C., Marsik, M., Papenfus, M., Toft, J., Verutes, G., Wood, S., Beck, M., Chan, F., Chan, K., Gelfenbaum, G., Gold, B., Halpern, B., Labiosa, W., Lester, S., Levin, P., McField, M., Pinsky, M., Plummer, M., Polasky, S., Ruggiero, P., Sutherland, D., Tallis, H., Day, A., Spencer, J., 2012. Modeling benefits from nature: using ecosystem services to inform coastal and marine spatial planning. International Journal of Biodiversity Science, Ecosystem Services & Management 8, 107–121.
Hill, A.C., 1971. Vegetation: a sink for atmospheric pollutants. J. Air Pollut. Control Assoc. 21, 341–346.
Jeon, S.W., Kim, J., Jung, H., 2013. A study on the forest classification for ecosystem services valuation. J. Korea Soc. Environ. Restor. Technol. 16, 31–39.
Jim, C.Y., Chen, W.Y., 2008. Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). J. Environ. Manage. 88, 665–676.
Jo, H.K., Cho, Y.H., Ahn, T.W., 2002. Capacity and value of atmospheric purification for Namsan Nature Park in Seoul. Korean J. Environ. Ecol. 16, 172–178.
KECO (Korea Environment Corporation), Air Korea, 2011, 2011. (accessed 20.04.15.). http://www.airkorea.or.kr/pastSearch.
KMA (Korea Meteorological Administration), 2011. http://www.kma.go.kr/weather/climate/average_30years.jsp (accessed 02.04.15.).
Kim, H.J., Jun, M.J., 2014. Analysis on relationship between urban development characteristics and air pollution level: a case of Seoul Metropolitan Region. Korea Plan. Assoc. 49, 151–167.
Kim, J.H., Kim, K.D., Kim, R.H., Park, C.Y., Yoon, H.J., Lee, S.W., Choi, H.T., Kim, J.J., 2010. A study on the estimation and the evaluation methods of public function of forest. Research Report. Korea Forest Research Institute 10–26.
Leh, M.D., Matlock, M.D., Cummings, E.C., Nalley, L.L., 2013. Quantifying and mapping multiple ecosystem services change in West Africa. Agric. Ecosyst. Environ. 165, 6–18.
Millennium Ecosystem Assessment, 2005. New Island, Washington, DC.
Maes, J., Braat, L.C., Jax, K., Hutchins, M., Furman, E., Termansen, M., Luque, S., Paracchini, M.L., Chauvin, C., Williams, R., Volk, M., Lautenbach, S., Kopperoinen, L., Schelhaas, M., Weinert, J., Goossen, M., Dumont, E., Strauch, M., Gorg, C., Dormann, C., Katwinkel, M., Zulian, G., Varjopuro, R., Ratamaki, O., Hauck, J., Forsius, M., Hengeveld, G., Perez-Soba, M., Bouraoui, F.I., Scholz, M., SchulzZunkel, C., Lepisto, A., Polishchuk, Y., Bidoglio, G., 2011. A spatial assessment of Ecosystem Services in Europe: methods, case studies and policy analysis—phase 1. PEER Interim Report. Ispra.
Maes, J., Hauck, J., Paracchini, M.L., Ratamäki, O., Hutchins, M., Termansen, M., Furman, E., Pérez-Soba, M., Braat, L., Bidoglio, G., 2013. Mainstreaming ecosystem services into EU policy. Curr. Opin. Environ. Sustain. 5, 128–134.
Nam, K., Lee, W.K., Kim, M., Kwak, D.A., Byun, W.H., Yu, H., Kwak, H., Kwon, T., Sung, J., Chung, D., Lee, S.H., 2015. Spatio-temporal change in forest cover and carbon storage considering actual and potential forest cover in South Korea. Sci. China Life Sci 58, 713–723.
National Institute of Environmental Research, 2012. Annual Report of Ambient Air Quality in Korea, 2011. Ministry of Environment, Sejong.
Ninan, K.N., Inoue, M., 2013. Valuing forest ecosystem services: case study of a forest reserve in Japan. Ecosyst. Serv. 5, 78–87.
Park, J.C., Kim, M.K., 2013. Comparison of precipitation distributions in precipitation data sets representing 1 km spatial resolution over South Korea produced by PRISM, IDW, and Cokriging. J. Korean Assoc. Geogr. Inf. Stud. 16, 147–163.
Pittock, J., Cork, S., Maynard, S., 2012. The state of the application of ecosystems services in Australia. Ecosyst. Serv. 1, 111–120.
Ramirez-Andreotta, M., Brusseau, M., Artiola, J., Maier, R., Gandolfi, A., 2014. Environmental Research Translation: enhancing interactions with communities at contaminated sites. Sci. Total Environ. 497–498, 651–664.
Rosenthal, A., Verutes, G., McKenzie, E., Arkema, K.K., Bhagabati, N., Bremer, L.L., Olwero, N., Vogl, A.L., 2015. Process matters: a framework for conducting decision-relevant assessments of ecosystem services. J. Biodivers. Sci. Ecosyst. Serv. Manage. 11, 190–204.
Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., Polasky, S., Ricketts, T., Bhagabati, N., Wood, S.A., Bernhardt, J., 2015. Notes from the field: lessons learned from using ecosystem service approaches to inform real-world decisions. Ecol. Econ. 115, 11–21.
SGIS (Statistical Geographic Information Service), 2012. URL: http://sgis.kostat.go.kr/contents/shortcut/shortcut_05.jsp (accessed 06.05.15.).
Schägner, J.P., Brander, L., Maes, J., Hartje, V., 2013. Mapping ecosystem services' values: current practice and future prospects. Ecosyst. Serv. 4, 33–46.
Smith, W.H., 2012. Air Pollution and Forests: Interactions Between Air Contaminants and Forest Ecosystems. Springer Science & Business Media, New York.
Son, Y.M., Kim, J.C., Lee, K.H., Kim, R.H., 2007. Forest biomass assessment in Korea. Research Report 07-22. Korea Forest Research Institute.
TEEB, 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB.
UK NEA, 2011. The UK National Ecosystem Assessment.
Vallero, D., 2014. Fundamentals of Air Pollution. Academic Press.
Wilson, M., Hoehn, J., 2006. Valuing environmental goods and services using benefit transfer: the state-of-the art and science. Ecol. Econ. 60, 335–342.