Assessing the Effect Between Green Space and Net Primary Productivity of Urban Forms using Remote Sensing and Structural Equation Modeling

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ABSTRACT: This study focuses on applying remote sensing and structural equation modeling (SEM) to assess the effect between green space and net primary productivity (NPP) of urban forms. The study area is Greater Taipei area in Taiwan, which includes two urban forms. One is Taipei City and the other is Taipei metropolitan area (i.e., Taipei City, New Taipei, and Keelung). The research processes include the calculation and selection of landscape indices, the NPP estimation using remote sensing, and the assessment of green space on the NPP between urban forms using the SEM. The results indicate as follows. (1) The green space of Taipei City is 65.44% in 2006 and the annual NPP is 2.09 ton/ha/yr. The effect of green space on the NPP is 0.86 according to the SEM established by six landscape indices, that is, percentage of landscape (PLAND), patch density (PD), largest patch index (LPI), mean Euclidean nearest neighbor distance (ENN_MN), area-weighted mean shape index (SHAPE_AM), mean patch size (AREA_MN). (2) The green space of Taipei metropolitan area is 86.32% in 2006 and the annual NPP is 3.20 ton/ha/yr. The effect of green space on the NPP is 0.93 under the established SEM by six landscape indices [PLAND, PD, LPI, ENN_MN, SHAPE_MN (mean shape index), CONTIG_AM (area-weighted mean contiguity index)]. (3) Assessing the effect between green space and NPP of two urban forms, Taipei metropolitan area is higher than Taipei City although two selected indices are different. From the above result, obviously remote sensing is a timely, economic, effective, and large-scale approach for the NPP estimation. Meanwhile, structural equation modeling is feasible to assess the effect of green space on the NPP between urban forms. The result obtained from this study can be a reference for the sustainable urban planning of Greater Taipei area in Taiwan.

1. INTRODUCTION

Urbanization is a trend due to economic development. However, it increases the amount of carbon dioxide and causes a serious problem recently. To achieve sustainable urban planning, most of previous studies focused on the reduction of carbon emission and few studies pay attention to carbon sequestration (Dhakal, 2004; Ewing & Rong, 2008). In fact, carbon sequestration such as the increase of urban green space can be regarded as an effective and useful task to eliminate the amount of carbon dioxide (IGBP, 1998). Therefore, how to increase urban green space and to improve the amount of carbon sequestration has become an important research topic. In Taiwan, similar situation occurred in urban area. Previous research are concerned about carbon emission and less concern about the carbon sequestration of urban green space (Cho, 2012). But this situation was changed gradually. At present, the relationship between green space and carbon sequestration is regarded as an important issue, particularly in urban area. As for the study of carbon sequestration, several methods have been proposed. For example, sampling of ground biomass, flux towers, model estimation, and remote sensing technique (Goetz & Prince, 1996; Gower, Kucharik & Norman, 1999; Zhu, 2005). Above methods are related to the estimation of carbon sequestration at three kinds of scales such as field-measurement, regional-scale, and global-scale. However, the International Panel on Climate Change proposes that remote sensing is a useful, timely, effective and economic technique to estimate carbon amounts for verifying national land use and land-use change (IPCC, 2003). Therefore, applications of remote sensing on carbon sequestration or net primary productivity (NPP) have been regarded as a common approach (Cheng, 2014; Zhu, 2005). Several studies applied SPOT image to estimate the NPP of Taiwan National Forest, Taipei City, and Taipei Metropolitan area (Cheng, 2014, 2015; Cheng & Chen, 2014; FBASO, 2011). However, the research referred to the direct effect of urban green space on the NPP is rare.

Due to the importance of carbon sequestration in sustainable urban planning, IPCC suggestion on applying remote sensing to estimate carbon sequestration, and few studies in assessing the effect of urban green space on the NPP, the objective of this study focuses on applying remote sensing and structural equation modeling (SEM) to assess the effect between urban green space and net primary productivity (NPP) of urban forms.

2. STUDY AREA AND MATERIALS

2.1 Study Area

The study area is Greater Taipei area, which located in the northern part of Taiwan (Fig. 1). It includes two urban forms. One is Taipei City (TC). The area covers about 27000 hectares and has 12 administrative districts. The other is Taipei Metropolitan Area (TMA). The area covers about 244,650 hectares and has 48 administrative districts which are distributed in Taipei City (12 districts), New Taipei City (29 districts), and Keelung City (7 districts).

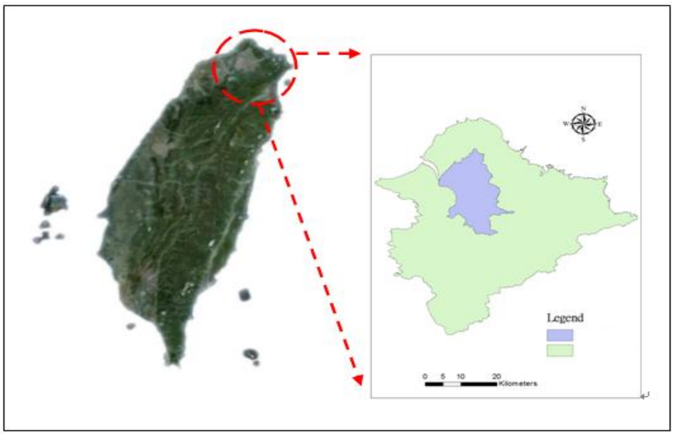
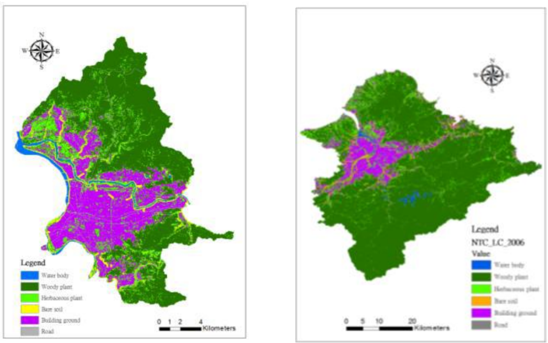


Fig. 1. Study area: Taipei City (blue color) and Taipei Metropolitan Area (blue & green color).

2.2 Materials

2.2.1 Land cover maps generated by SPOT image: SPOT images (pixel size= 20m×20m) in 2006 are first classified to generate the land cover maps of Taipei City and Taipei Metropolitan Area. Fig. 2 is the land cover maps of two urban forms in 2006. The classification accuracies according to test area are above 85%. The categories of land cover map of urban forms include 6 cover types (i.e., woody plants, WP; herbaceous plants, HP; water body, WB; bare soil, BS; building ground, BG; and road, RD). However, this study focuses on urban green space. Therefore, the generated land cover map are further grouped into a land cover map with green space (i.e., woody plants; herbaceous plants) and non-green space (i.e., water body; bare soil; building ground; and road). The result points out that the percent of green space and non-green space of Taipei City is 65.44% and 34.56%. As for Taipei Metropolitan Area, the percent of green space is 86.32% and 13.68% for non-green space.



(a) (b)

Fig. 2. Land cover maps of (a) Taipei City and (b) Taipei Metropolitan Area in 2006

2.2.2 Meteorological data: Three kinds of meteorological data in 2006 are also needed to estimate the NPP of two urban forms. They are total monthly precipitation, mean monthly temperature, and total monthly solar radiation. Above three meteorological data are provided by Taiwan Typhoon and Flood Research Institute and further interpolated at the same scale with the SPOT image using the CoKriging method under the geostatistical analysis of ArcGIS 10.2 software. Meanwhile, the paired t-test is used to detect the difference between the actual data and the interpolated data of meteorological stations. The result shows no significant differences under the 99% significance level.

3. METHODS

To achieve the objective of assessing the effect of green space on the NPP between Taipei City and Taipei Metropolitan Area, the methods include the calculation and selection of landscape indices for the SEM establishment, the NPP estimation using remote sensing, and the assessment of green space on the NPP using the SEM.

3.1 Calculation and selection of landscape indices for the SEM establishment

This study emphasizes the effect of green space (i.e., vegetation type) on the NPP. Therefore, the land cover map with green space and non-green space was first applied to calculate the landscape indices of green space for two urban forms using the FRAGSTATS program of spatial pattern analysis (McGarigal and Marks, 1995). There are three kinds of landscape indices, that is, patch-level, class-level, and landscape-level. This study focuses on the class-level indices of green space and assumes only 6 landscape indices related to green space coverage will be used to establish the SEM. However, urban forms have different landscape indices. Thus the correlation between green space coverage and landscape indices are first calculated. After that, 6 class-level indices with higher correlation are further selected for Taipei City and Taipei Metropolitan Area. As for the detailed calculation of landscape indices using the FRAGSTATS program, please refers to the FRAGSTATS manual.

3.2 NPP estimation using remote Sensing

After the calculation and selection of landscape indices, next is the NPP estimation between urban forms using SPOT image in 2006. The steps include (1) the calculation of vegetation indices such as NDVI and SR, (2) the estimation of fraction of photosynthetically active radiation (FPAR) and photosynthetically active radiation absorbed by green plants (APAR), and (3) the estimation of NPP based on monthly precipitation (W), monthly temperature (T), and monthly solar radiation (SOL). Fig. 3 is the flowchart of NPP estimation using SPOT image. Detailed information about the equations and variables please referred to Cheng (2014).

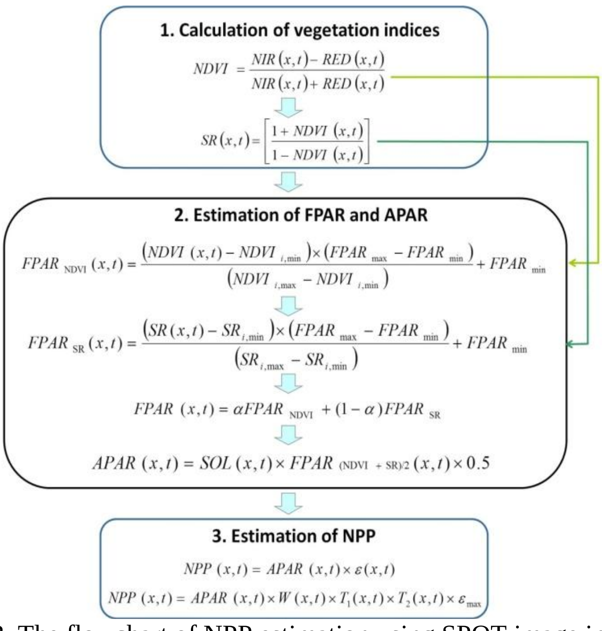


Fig. 3. The flowchart of NPP estimation using SPOT image in 2006

3.3 Assessment of green space effect on the NPP using the SEM

To assess the effect between green space and NPP of urban forms, this study applied the AMOS (Analysis of Moment Structure) software to establish the SEM between green space and NPP. The observation data are 12 districts of Taipei City and 48 districts of Taipei Metropolitan Area. In fact, SEM is a multivariate analysis technique called "Analysis of Covariance Structure" and AMOS software is a useful graphic tool to integrate factor analysis (i.e., confirmatory factor analysis) with path analysis for "Analysis of Covariance Structure". The analytical steps of the SEM are as follows.

(1) SEM establishment for the effect of green space on NPP : Three types of variables are needed. They are latent variable, observed variable, and error variable. In this study, latent variables are green space and NPP. The former is "exogenous variable" while the latter is "endogenous variable". As for the observed variables, the green space coverage is the above selected 6 class-level indices and the NPP is temperature and rainfall.

(2) Model specification and identification: A series of equations and path diagrams are used to examine the model specification and identification and make sure each parameter in the model can be estimated.

(3) Standardization of observed variables: The unit of observed variables for green space coverage and NPP may be different, therefore standardization is needed before analysis.

(4) Model estimation: A generalized least square (GLS) of multiple regression is used to estimate the model parameters.

(5) Assessment of fit: To assess the fit between the established model and the collected data, it includes the assessment of overall model, measurement model, and structure model. The step is overall model first. If the assessment with Chi Square is acceptable, then continue the fit assessment of measurement and structure model using he construct validity and the extracted average variance. Otherwise, go directly to the model modification.

(6) Model modification: If the assessment of fit is not acceptable, then model modification is performed until the assessment of fit is acceptable.

(7) SEM Explanation: If the assessment of fit for overall model, measurement model and structure model are acceptable, then further analyze the direct effect of urban green space on the NPP based on the established SEM.

4. RESULTS AND DISCUSSION

4.1 Landscape indices of green space between urban forms

As mentioned previously, this study assumed only 6 class-level indices for the coverage of green space. After the correlation calculation, the 6 indices for Taipei City are percent of landscape (PLAND), patch density (PD), largest patch index (LPI), mean Euclidean nearest neighbor distance (ENN_MN), area-weighted mean shape index (SHAPE_AM), mean patch size (AREA_MN). As for Taipei Metropolitan Area, the 6 indices are PLAND, PD, LPI, ENN_MN, and mean shape index (SHAPE_MN), area-weighted mean contiguity index (CONTIG_AM). Table 1 is the selected 6 class-level indices of two urban forms. Clearly, the 6 class-level indices between two urban forms are different.

Table 1. The selected 6 landscape indices between two urban forms.

	Landscape Indices
Taipei City	PLAND, PD, LPI, ENN_MN, **SHAPE_AM, AREA_MN**
Taipei Metropolitan Area	PLAND, PD, LPI, ENN_MN, **SHAPE-MN, CONTIG_AM**

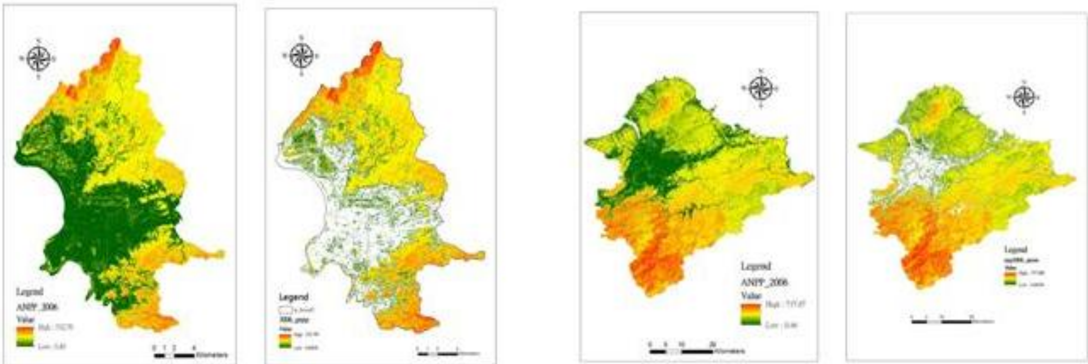
4.2 NPP estimates of two urban forms using remote sensing

Table 2 is the NPP estimate for two urban forms using SPOT image in 2006. It includes the annual NPP and total NPP between entire urban area and green space area. Obviously, the annual NPP estimates of entire urban area for Taipei City and Taipei Metropolitan Area are 1.42 ton/ha/yr and 2.83 ton/ha/yr while the annual NPP estimates of green space area are 2.09 ton/ha/yr and 3.20 ton/ha/yr. As for the total NPP estimates of entire urban area, Taipei City and Taipei Metropolitan Area are 3.82 $x10^4$ ton/yr and 69.23 $x10^4$ ton/yr, and 3.70 $x10^4$ ton/yr and 67.58 $x10^4$ ton/yr for the green space area.

Comparing the annual NPP estimates of green space area between two urban forms, clearly Taipei Metropolitan Area is higher than Taipei City. The difference results from the percent of green space between two urban forms. Fig. 4 is the NPP distribution map of two urban forms between entire urban area and green space area.

Table 2. NPP estimates of entire urban area and green space area between two urban forms

	Entire urban area		Green space area	
	Annual NPP (ton/ha/yr)	Total NPP (10^4 ton/yr)	Annual NPP (ton/ha/yr)	Total NPP (10^4 ton/yr)
Taipei City	1.42	3.82	2.09	3.70
Taipei Metropolitan Area	2.83	69.23	3.20	67.58



Entire urban area Green space area Entire urban area Green space area

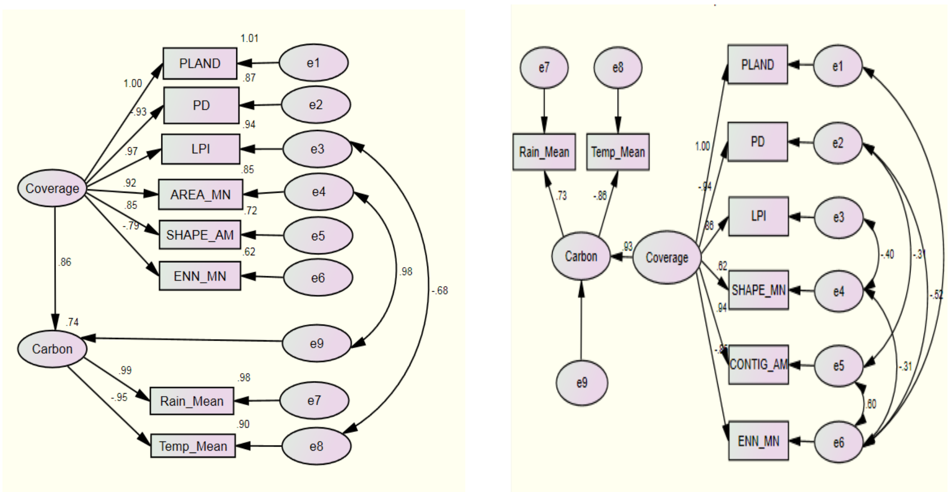
(a) (b)

Fig. 4. The NPP maps of entire urban area and green space area between (a) Taipei City and (b) Taipei Metropolitan Area.

4.3 Assessment of green space effect on the NPP between urban forms using the SEM

Fig. 5 is the SEM diagrams of two urban forms, which are established for assessing the effect of "coverage" (i.e., green space) on the carbon (i.e., NPP). From the SEM diagram of Taipei City (Fig. 5a), the calculated Chi Square with degree of freedom (=17) is 21.89 and its probability (=0.19) is larger than 0.01. This indicates the established SEM is acceptable under 1% significant level and the goodness-of-fit of the model is good. Meanwhile, root mean square error of approximation (RMSEA) is also used to test the model goodness-of-fit. The result shows acceptable goodness-of-fit because the calculated RMSEA (=0.16) is close to the threshold value (= 0.1). As for the SEM diagram of Taipei Metropolitan Area (Fig. 5b), the calculated Chi Square with degree of freedom (=13) is 12.74 and its probability (=0.47) is larger than 0.01. The result also indicates the established SEM is acceptable under 1% significant level and the model goodness-of-fit is good. Besides, the RMSEA (=0.00) is less than 0.1, thus the goodness-of-fit is pretty good.

Furthermore, to assess the model fit of the exogenous variable, the construct validity and the extracted average variance for "coverage" are calculated and shown in Table 3. From the result of Taipei City, the construct validity of "coverage" is 0.80 which means the inner quality of the established SEM is good because it is larger than the standard value (=0.6). As for the extracted average variance (=0.83), the value indicates the selected 6 observed variables can explain the latent variable of "coverage" well because it is larger than the standard value (=0.5). Finally, the direct effect of green space on the NPP is strong because the value is 0.86. On the other hand, the result obtained from Taipei Metropolitan Area is as follows. The calculated construct validity (=0.65) is larger than the standard value (=0.6) and the extracted average variance (=0.76) is also larger than the standard value (=0.5). This result indicates the inner quality of the established SEM is good. In addition, the direct effect of green space on the NPP is pretty strong because the value is 0.93. Comparing the direct effect between two urban forms, clearly Taipei Metropolitan Area is stronger than Taipei City.



(a) (b)

Fig. 5. The SEM diagram of (a) Taipei City and (b) Taipei Metropolitan Area.

Table 3. Assessment of green space effect on the NPP between urban forms using the SEM

	Established SEM		Model goodness-of-fit	Assessment of model fit		Direct effect of SEM
	x^2 with d.f.	x^2 Prob. (0.01)	RMSEA	Construct validity (>0.6)	Average variance (>0.5)	
TC	21.89	0.19	0.16	0.80	0.83	**0.86**
TMA	12.74	0.47	0.00	0.65	0.76	**0.93**

**TC: Taipei City; TMA: Taipei Metropolitan Area.

Some discussions from this study are as follows. (1) Landscape indices for the SEM establishment: In fact, more than 6 class-level indices are correlated with the coverage of green space. However, this study assumed only 6 landscape indices for establishing the SEM of urban forms. (2) NPP estimation using SPOT image: Due to the problem of terrain and climate in Taiwan, it is difficult to acquire monthly SPOT image for the annual NPP estimation. To eliminate the problem, this study applied two periods (dry and wet seasons) of SPOT images to estimate the NPP of urban forms. The result seems feasible. (3) SEM establishment for assessing the effect of green space on the NPP: This study selected 6 landscape indices to establish the SEM of urban forms. From the result, the direct effect of green space on the NPP is 0.86 for Taipei City and 0.93 for Taipei Metropolitan Area. Obviously, Taipei Metropolitan Area is stronger effect than Taipei City. The reason may result from the difference of green space area.

5. CONCLUSION

This study applied remote sensing and structural equation modeling (SEM) to assess the effect of urban green space on the NPP between Taipei City and Taipei Metropolitan Area in 2006. The research processes include the calculation and selection of landscape indices, the NPP estimation using remote sensing, and the assessment of green space effect on the NPP between urban forms using the SEM. The result indicates Taipei City has 65.44% green space and the annual NPP is 2.09 ton/ha/yr. Based on the selected 6 landscape indices (i.e., PLAND, PD, LPI, ENN_MN, SHAPE_AM, AREA_MN**)** to establish the SEM, the direct effect of green space on the NPP is 0.86. As for the result from Taipei Metropolitan Area, the percent of green space is 86.32% and the annual NPP is 3.20 ton/ha/yr. In addition, the direct effect of green space on the NPP is 0.93 according to the selected 6 landscape indices (i.e., PLAND, PD, LPI, ENN_MN, SHAPE-MN, CONTIG_AM). Comparing the direct effect between two urban forms, clearly Taipei metropolitan area is strongly higher than Taipei City. The above result can be concluded that remote sensing is a timely, economic, effective, and large-scale approach for the calculation of urban green space and the estimation of NPP. Meanwhile, the established SEM is feasible to assess the effect of green space on the NPP between urban forms. The result from this study can be a reference for the sustainable urban planning of Greater Taipei area.

6. ACKNOWLEDGEMENTS

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