EFFECT OF URBAN GREEN SPACE ON THE NET PRIMARY PRODUCTIVITY USING REMOTE SENSING AND STRUCTURAL EQUATION MODELING

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ABSTRACT: Carbon issue has become an important research topic in urban sustainable development recently. This study applies remote sensing technique to estimate urban green space and net primary productivity (NPP) of Taipei City in 2002 and 2006. The objective is to investigate the effect of urban green space on the NPP using structural equation modeling (SEM). The research processes include the analysis of landscape change using landscape indices and Shannon diversity t-test, the NPP estimation using SPOT image, and the investigation of green space effect on the NPP using the SEM. The results indicate as follows. (1) The green space of Taipei City in 2002 is 63.56% (i.e., 51.46% woody plants and 12.10% herbaceous plants) and 65.49% in 2006 (i.e., 48.99% woody plants and 16.50% herbaceous plants). Meanwhile, Taipei's landscape change is significantly different from 2002 to 2006, according to the Shannon diversity index (SHDI) and SHDI t-test. (2) The annual NPP in 2002 is 160 $gC/m^2/yr$ and 142 $gC/m^2/yr$ in 2006. The result shows that the trend of annual NPP decreases from 2002 to 2006. (3) Based on the structural equation modeling established by the selected six landscape indices, the direct effect of urban green space on NPP is 0.90 in 2002 and 0.86 in 2006. This result illustrates that the effect of urban green space on the NPP is pretty strong in 2002 and 2006. From the above result, it can be concluded that remote sensing is a timely, economic, and effective approach for the analysis of landscape change and the estimation of NPP. Meanwhile, structural equation modeling is feasible to investigate the effect of urban green space on NPP. The result obtained from this study can be a reference for the sustainable urban planning of Taipei City.

1. INTRODUCTION

Urbanization is a trend due to economic development,. However, it increases the amount of carbon dioxide and causes a serious problem recently. Therefore, many research focused on the reduction of carbon emission and rare in carbon sequestration. However, to achieve sustainable urban planning, the improvement of carbon sequestration is also regarded as an important research topic, for example, the increase of urban green space. Similar situation occurred in Taiwan. Most of previous research focus on the carbon emission in urban area, but less concern about carbon sequestration of urban green space (Cho, 2012). But this situation was changed recently. The effect of urban green space on carbon sequestration is regarded as an important research topic, particularly in urban area. In fact, several methods have been proposed in the study of carbon sequestration, for example, sampling of ground biomass, flux towers, model estimation, and remote sensing technique (Goetz & Prince, 1996; Gower, Kucharik & Norman, 1999). Those techniques 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, application of remote sensing on net primary productivity (NPP) has been become a common approach in carbon sequestration (Zhu, 2005; Cheng, 2014). Among the NPP studies, Cheng (2014) applied SPOT image in 2006 to estimate the NPP of Taiwan National Forest and then made a comparison between remote sensing and field sampling approaches. However, few studies focuses on the relationship between urban green space and NPP.

Due to the importance of carbon sequestration in sustainable urban planning and IPCC suggestion on applying remote sensing to estimate carbon sequestration, this study applies remote sensing technique to estimate Taipei's urban green space and NPP in 2002 and 2006. The objective is to investigate the effect of urban green space on the NPP using structural equation modeling (SEM).

2. STUDY AREA AND MATERIALS

2.1 Study Area

The study area is Taipei City which located in the northern part of Taiwan (Fig. 1). The area covers about 27000 hectares. The terrain is higher in the northeast and southeast regions. The climate is characterized as sub-tropical with seasonal monsoons. There are 12 administrative districts in Taipei City. They are Beitou (BT), Shilin (SL), Datong (DT), Zhongshan (ZS), Songshan (SS), Neihu (NH), Wanhua (WH), Zhongzheng (ZZ), Daan (DA), Xinyi (XY), Nangang (NG), and Wenshan (WS) districts.

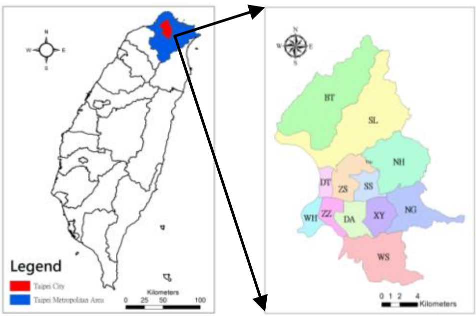


Fig. 1. Study area-Taipei City.

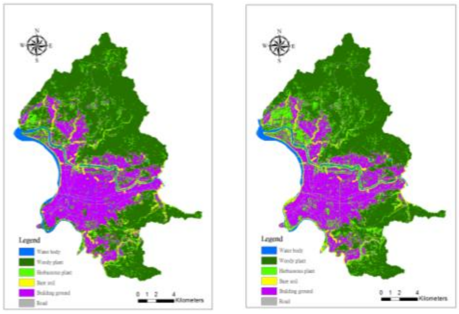


Fig. 2. Taipei's land cover map in (left) 2002; (right) 2006.

2.2 Materials

2.2.1 SPOT image and land cover map: SPOT images (pixel size= 20m×20m) in 2002 and 2006 are applied to calculate the vegetation indices and then estimate the NPP of Taipei City. In addition, the land cover maps in 2002 and 2006 are obtained from SPOT image classification. The classification accuracies based on test area are above 85%. The categories of land cover map include 6 types (i.e., woody plant, herbaceous plant, bare soil, water body, building ground, and road). Fig. 2 is the land cover map of Taipei City in 2002 and 2006.

2.2.2 Meteorological data: To estimate the NPP in 2002 and 2006, three kinds of meteorological data are needed. 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 there is no significant differences under the 99% significance level.

3. METHODS

3.1 Landscape change analysis using landscape indices and Shannon Diversity t-test

The FRAGSTATS program of spatial pattern analysis (McGarigal and Marks, 1995) is applied to calculate two kinds of landscape indices of Taipei City. One is the class-level index. The other is the landscape-level index.

3.1.1 Class-level indices: 6 class-level indices related to green space are first selected to compare Taipei's cover type differences between 2002 and 2006 and further establish the structure equation model for investigating the effect of urban green space on the NPP. They are PLAND, PD, LPI, AREA_MN, SHAPE_AM, ENN_MN. Detailed information about equation, unit and range, and description of 6 class-level indices can be found in FRAGSTATS manual (McGarigal and Marks, 1995).

3.1.2 Landscape-level indices: Landscape-level index such as Shannon Diversity Index (SHDI) is selected to compare Taipei's landscape change from 2002 to 2006. The equation of SHDI is as follows.

$$SHDI = -\Sigma (P_i * \ln P_i) \qquad \text{.....................................(1)}$$

where P_i = proportion of the landscape occupied by patch type (class) i, and SHDI ≥ 0, without limit.

Furthermore, the Shannon diversity t-test (Hutcheson, 1970) as equation (2) is applied to examine if the landscape of Taipei City has a significant change from 2002 to 2006.

$$t = \frac{(H_1 - H_2)}{(VarH_1 + VarH_2)^{1/2}} \qquad \text{.....................................(2)}$$

where H_i is the Shannon diversity index of i urban form; $VarH_i$ is the variance; and df is the degree of freedom.

$$H_i = -\sum_{i=1}^{m} p_i \times \ln(p_i) - \frac{m-1}{n_i} \quad \text{.....................................(3)}$$

$$VarH_i = \frac{\sum_{i=1}^{m} p_i (\ln(p_i))^2 - \left(\sum_{i=1}^{m} p_i \times \ln(p_i)\right)^2}{n_i} + \frac{m_i - 1}{2{n_i}^2} \quad \text{................(4)}$$

$$df = \frac{(VarH_1 - VarH_2)^2}{\frac{(VarH_1)^2}{n_1} + \frac{(VarH_2)^2}{n_2}} \quad \text{.....................................(5)}$$

3.2 NPP estimation in 2002 and 2006 using SPOT image

The NPP estimation of Taipei City using SPOT image in 2002 and 2006 includes (1) the calculation of vegetation indices, (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. Fig. 3 is the flowchart of NPP estimation using SPOT image. Detailed information about the equations and descriptions please referred to Cheng (2014).

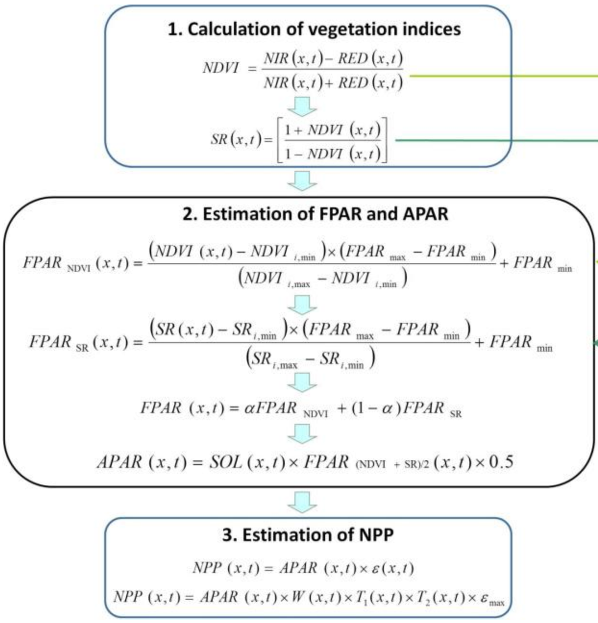


Fig. 3. The flowchart of NPP estimation from SPOT data.

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

To investigate the effect of Taipei's urban green space on the NPP, this study applies AMOS (Analysis of Moment Structure) software to establish the SEM between urban green space and NPP. The observation data are 12 administrative districts of Taipei City. 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 step of SEM is 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 of green space, previous 6 class-level indices (i.e., PLAND, PD, LPI, AREA_MN, SHAPE_AM, ENN_MN) are selected. Meanwhile, the observed variables of NPP are 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 asses 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) Explanation of SEM: 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 change analysis based on landscape indices and Shannon Diversity t-test

Table 1 is the class-level indices of Taipei's cover types in 2002 and 2006. Because this study focuses on green space (i.e., vegetation type) and its effect on NPP, six cover types are then classified into vegetation type (i.e., woody plants, WP; herbaceous plants, HP) and non-vegetation type (i.e., water body, WB; bare soil, BS; building ground, BG; and road, RD). From the PLAND of Table 1, clearly woody plants decrease 2.47% and herbaceous plants increase 3.40% in five years, although the PLAND of vegetation type increases from 63.56% to 65.49%. Meanwhile, other five class-level indices of woody and herbaceous plants also show a change from 2002 to 2006. As for the landscape-level index of Taipei's cover types, the result indicates the SHDI in 2002 and 2006 are 1.256 and 1.276, respectively. According to the calculated Shannon diversity t-test, the t value (=64.95) is greater than the table value (=1.96) under the significance level of 5%. Therefore, the landscape change of Taipei City from 2002 to 2006 is quite significant.

Table 1. Class-level indices of Taipei's landscape in 2002 and 2006.

Type	PLAND		PD		LPI		AREA_MN		SHAPE_AM		ENN_MN	
	2002	2006	2002	2006	2002	2006	2002	2006	2002	2006	2002	2006
WB	3.37	2.69	4.87	1.49	1.48	1.18	0.69	1.80	3.77	3.32	111.29	172.47
WP	51.46	48.99	6.25	10.59	19.59	19.31	8.23	4.62	10.16	15.38	74.73	65.52
HP	12.10	16.50	23.83	37.38	0.27	0.77	0.51	0.44	3.91	5.59	59.44	52.44
BS	4.22	3.79	6.68	8.63	0.24	0.19	0.63	0.44	3.10	3.64	86.77	78.08
BG	27.58	26.77	5.56	9.42	4.51	4.26	4.96	2.84	7.59	10.69	84.94	67.05
RD	1.27	1.27	0.03	0.03	1.16	1.16	49.07	49.10	40.13	40.09	624.92	616.69

4.2 NPP estimates of Taipei City and Taipei green space in 2002 and 2006

Table 2 is the NPP estimate of Taipei City and Taipei's green space in 2002 and 2006 based on SPOT image. From Table 2, the annual NPP estimates of Taipei City in 2002 and 2006 are 1.60 ton/ha/yr and 1.42 ton/ha/yr while the total NPP estimates in 2002 and 2006 are 4.317 $x10^4$ ton/yr and 3.821 $x10^4$ ton/yr. Obviously the NPP in 2002 is larger than that in 2006. This may result from the decrease of woody plants in 2006. Furthermore, the NPP estimates of Taipei's green space are also calculated because this study focuses on the NPP of green space. The result indicates the annual NPP is 2.48 ton/ha/yr in 2002 and 2.09 ton/ha/yr in 2006. Meanwhile, the total NPP is 4.26 $x10^4$ ton/yr in 2002 and 3.71 $x10^4$ ton/yr in 2006. If compare the annual NPP (ton/ha/yr) in 2002 or 2006, Taipei's Green Space is almost 1.5 times of Taipei City. Fig. 4 is the NPP distribution map of Taipei City and Taipei's green space in 2002 and 2006.

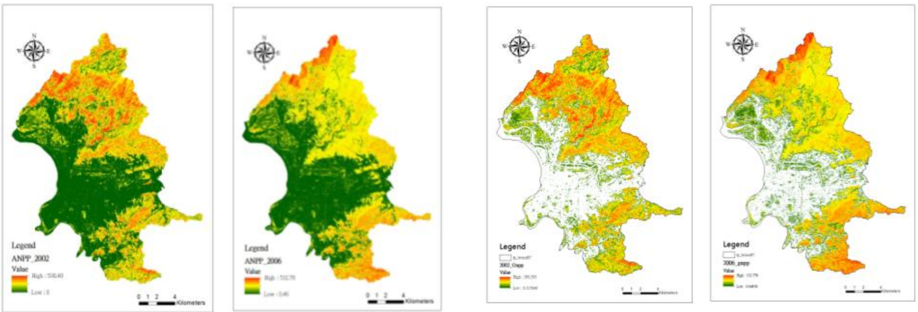
Table 2. NPP estimates of Taipei City and Taipei's green space in 2002 and 2006 based on SPOT image

	Taipei City		Taipei Green Space	
	Annual NPP (ton/ha/yr)	Total NPP (10^4 ton/yr)	Annual NPP (ton/ha/yr)	Total NPP (10^4 ton/yr)
2002	1.60	4.32	2.48	4.26
2006	1.42	3.82	2.09	3.71

4.3 Effect of urban green space on the NPP in 2002 and 2006 using the SEM

Fig. 5(a) and 5(b) are the SEM diagrams established for investigating the effect of "coverage" (i.e., green space) on the carbon (i.e., NPP) in 2002 and 2006. From the SEM in 2002, the calculated Chi Square with degree of freedom (=17) is 12.99 and its probability (=0.74) is larger than 0.01. This indicates the established SEM is acceptable under

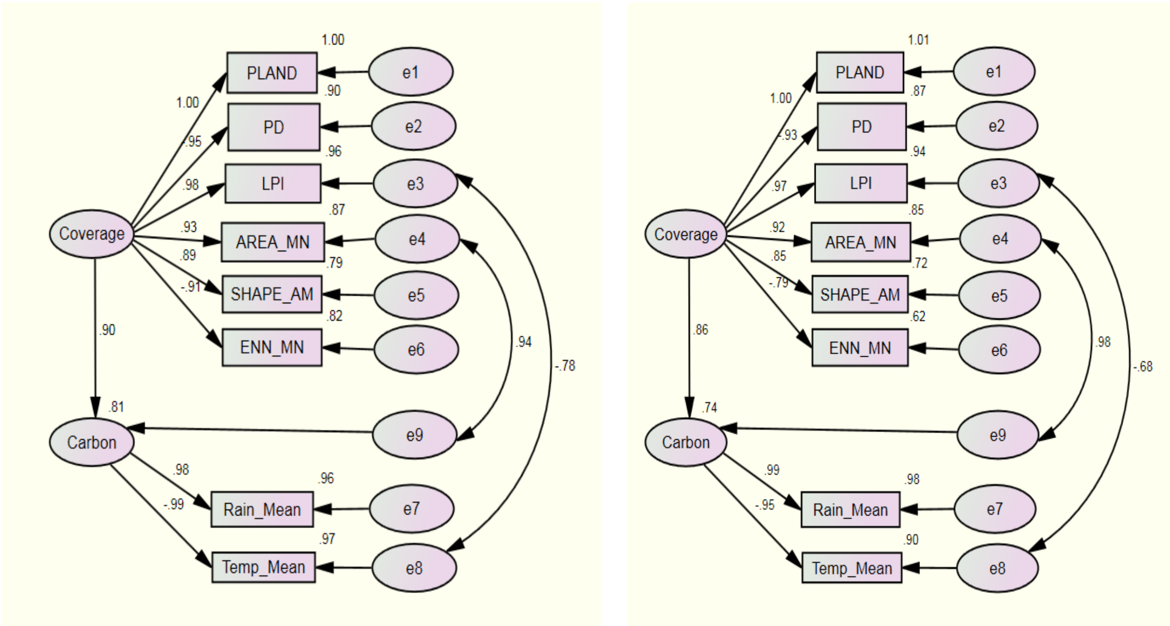
1% significant level and the goodness-of-fit of the model is pretty good. Meanwhile, root mean square error of approximation (RMSEA) is also used to test the model goodness-of-fit and the result shows nice goodness-of-fit because the calculated RMSEA (=0) is less than the threshold value (= 0.1). As for the SEM in 2006, the calculated Chi Square with degree of freedom (=17) is 21.89 and its probability (=0.19) 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 (=0.16) is close to 0.1, thus the goodness-of-fit is regarded as acceptable.



(a) Taipei City (b) Taipei's green space

Fig. 4. The NPP distribution map of (a) Taipei City and (b) Taipei's green space in 2002 (left) and 2006 (right).

Furthermore, to further assess the model fit of the exogenous variable in 2002 and 2006, the construct validity and the extracted average variance for "coverage" are calculated and shown in Table 3. From the result obtained in 2002, the construct validity of "coverage" is 0.85 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 (=0.89), 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, according to the SEM diagram in 2002, clearly the influence of urban green space on NPP in 2002 is strong and the value of direct effect is 0.90. On the other hand, the result obtained in 2006 is pretty similar to that in 2002. For example, the calculated construct validity is larger than the standard value (e.g., 0.80>0.6) and the extracted average variance is also larger than the standard value (e.g., 0.83>0.5). These results indicate the inner quality of the established SEM is good. In addition, the influence of urban green space on the NPP in 2006 is strong because the value of direct effect is 0.86.



(a) (b)

Fig. 5 The SEM established for green space effect on the NPP in (a) 2002 and (b) 2006.

Table 3 Assessment of the model fit for exogenous variable (i.e., green space) in 2002 and 2006

	Construct validity	Extracted average variance
2002	0.85	0.89
2006	0.80	0.83

Some discussions from this study are as follows. (1) Landscape change analysis using landscape indices: This study selected 6 landscape indices to analyze Taipei's landscape change between 2002 and 2006. The reason is because the SEM established for green space effect on the NPP is under the assumption of 6 landscape indices. In fact, more than 6 indices are correlated with green space. (2) NPP estimation using SPOT image: Some problems occurred during the NPP estimation of SPOT image, for example, the collection of maximum light use efficiency of vegetation types and the acquisition of SPOT monthly image in Taiwan. To eliminate these problems, the simulation of maximum light use efficiency for vegetation types and the use of two periods of SPOT images were adopted (Cheng, 2014). The result seems feasible. (3) SEM establishment for the effect of green space on the NPP: In this study, 6 landscape indices are selected to establish the SEM in 2002 and 2006. From the result of green space on the NPP, the direct effect in 2002 is 0.90 and 0.86 in 2006. The direct effect decreases from 2002 to 2006. The reason may result from the decrease of woody plants in 2006 according to the PLAND of green space in Table 1 and the annual NPP in Table 2.

5. CONCLUSION

The objective of this study is to investigate the effect of Taipei's green space on the NPP using remote sensing and the structural equation modeling. The research process includes three parts. The first part is to apply landscape indices and Shannon diversity t-test to analyze the landscape change of Taipei City. The result indicates Taipei's green space in 2002 is 63.56% (i.e., 51.46% woody plant and 12.10% herbaceous plant) and 65.49% in 2006 (i.e., 48.99% woody plant and 16.50% herbaceous plant). Meanwhile, Taipei's landscape change between 2002 to 2006 is significantly different according to the Shannon diversity t-test. The second part is the NPP estimation using remote sensing. The result shows that the annual NPP of Taipei city is 1.60 ton/ha in 2002 and 1.42 ton/ha in 2006 while the annual NPP of Taipei green space is 2.48 ton/ha in 2002 and 2.09 ton/ha in 2006. Obviously the NPP in 2002 is larger than that in 2006, which may result from the decrease of woody plants in 2006. The third part focuses on the relationship between green space and the NPP using the established structural equation modeling. The result illustrates that the direct effect of urban green space on the NPP is 0.90 in 2002 and 0.86 in 2006. Obviously the effect of Taipei's green space on the NPP is pretty significant although the effect is decreasing because the area of woody plants in 2006 is smaller than that in 2002. The above result can be concluded that remote sensing is a timely, economic, and effective approach for the analysis of landscape change and the estimation of NPP. In addition, the establishment of structural equation modeling is feasible to illustrate the effect of green space on the NPP. The result obtained from this study can be a reference for the sustainable urban planning of Taipei City.

6. ACKNOWLEDGEMENTS

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