MONITORING CHANGES OF ECOSYSTEM SERVICES SUPPLY AND DEMAND PATTERN IN CENTRAL AND SOUTHERN LIAONING URBAN AGGLOMERATIONS, CHINA USING LANDSAT IMAGES

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ABSTRACT:

Indentifying the spatio-temporal patterns of ecosystem services supply and demand and the driving forces is of great significance to the regional ecological security and sustainable socio-economic development. Due to long term and high-intensity development, the ecological environment in central and southern Liaoning urban agglomerations has been greatly destroyed thereafter has restricted sustainable development in this region. Based on Landsat ETM and OLI images, land use of this urban agglomeration in 2005, 2010 and 2015 was extracted. The integrative index of multiple-ecosystem services (IMES) was used to quantify the supply ($IMES_s$), demand ($IMES_d$) and balance ($IMES_b$) of multiple-ecosystem services, The spatial patterns of ecosystem services and its dynamics for the period of 2005-2015 were revealed. The multiple regression and stepwise regression analysis were used to explore relationships between ecosystem services and socioeconomic factors. The results showed that the $IMES_s$ of the region increased by 2.93%, whereas $IMES_d$ dropped 38%. The undersupplied area was reduced to 2. The $IMES_s$ and $IMES_b$ were mainly negatively correlated with gross domestic product (GDP), population density, foreign investment and industrial output, while GDP per capita and the number of teachers had significant positive impacts on ecosystem services supply. The positive correlation between $IMES_d$ and GDP, population density and foreign investment were found. The ecosystem services models were established. Supply and balance of multiple-ecosystem services were positively correlated with population density, but the demand was the opposite. The results can provide some reference value for the coordinately economic and ecological development in the study area.

1. INTRODUCTION

As the material foundation and basic condition of human existence and development, ecosystem services are the key natural capital owned by mankind. Human obtain various benefits from multiple-ecosystem (Costanza,1997). Multiple-ecosystem services are usually quantified by using monetary methods. However, most ecosystem services are non-market-oriented and their economic value cannot be quantified. Burkhard (Burkhard et al., 2012) put forward the concept of "ecosystem" of ecosystem services, taking into account the non-market factors. He thinks that we need to study the supply and demand of ecosystem services and their relationship. Ecosystem services will change due to rapid urbanization and land-use change (Liu et al., 2008). At present, many efforts have been made to evaluate supply and demand of ecosystem services at small and medium spatial scale and focused on static studies (Ma et al., 2017). From the perspective of human and economic development, it is important to maintain and enhance the supply of multiple-ecosystem services. How to bring ecosystem services into management decisions is not only a major scientific issue facing the protection of regional ecological security, but also a frontier research topic in the field of international ecology.

China has experienced profound changes in the spatial structure of urban areas during the past several decades. Central and southern Liaoning urban agglomeration has pioneered the northeast China in urbanization processes and economic development. In the past 10 years, urban land use changed significantly, including a large area of green ecological reclamation, land degradation, desertification, and deterioration of the ecological environment. To date, the comparative analysis of multiple-ecosystem services associate with the urbanization dynamics is still lacking. The objective of this paper is (1) to depict the spatial and temporal pattern of ecosystem service supply and demand in central and southern Liaoning urban agglomerations from 2005 to 2015, (2) to evaluate the influence of social economic factors and the supply and demand of ecosystem services. The study will help understand the relationship between natural resources and human environment, and provide a reference for environmental management and policy decision (Swetnam et al., 2011). It will promote social economic and sustainable development of resources and environment in the central and southern Liaoning urban agglomerations.

2. STUDY AREA

Central and southern Liaoning urban agglomerations in this study(38 °to 43 °N, 121 °to 125 °E) is located in the south of northeast China, with the land area of 6.41 $\times 10^4$ km^2.In 2015, the population was 23.1938 million and the GDP was 1.9 $\times 10^4$ billion RMB Yuan. Taking Shenyang as the centre and Dalian

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as a secondary centre, including Tieling, Panjin, Yingkou, Liaoyang, Dandong, Benxi, Fushun and Anshan, the proportion of urban density and large city in this region is very high(Han,2013). The area is located in the temperate semi-humid monsoon climate zone, with an average annual temperature of 6-9℃. Its economic development is based on mineral, ocean and agricultural resources. This urban agglomeration has gradually become one of the important bases of steel industry, chemical industry and agricultural production in the nation.

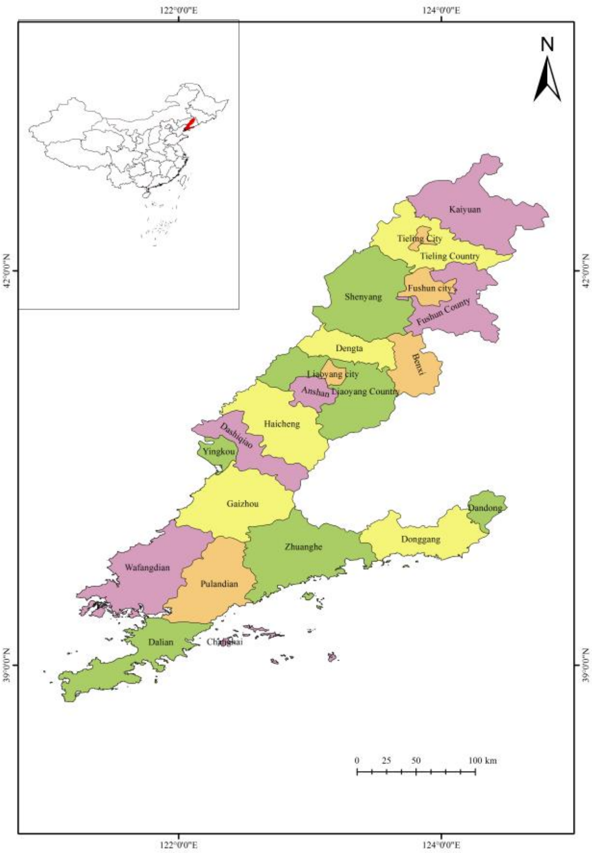

Figure 1. Study area

3. DATA AND METHOD

3.1 Data and Its Preprocessing

In this study, we used the Landsat ETM+ and OLI images in the years of 2005, 2010 and 2015 as the basic data. Totally thirty scenes were obtained from the U.S. Geological Survey (USGS) (https://glovis.usgs.gov/). The images were from June to September, with less cloud or cloudy-free. The resolution of the images is 30m. The land cover/land use classification was visually interpreted using the eCognition software. After many experiments, the segmentation criteria selected in the classification was: a segmentation scale of 10, a shape factor of 0.1, and a compactness factor of 0.5. Finally, the typical area was selected as a sampling point and performed the field survey and data collection for accuracy verification. The classification accuracy was about 83% which met the research requirements. Based on the major ecosystems in the study area and the categories of global land cover datasets, 15 land cover types were finally identified as rivers (water channels), paddy fields, dry land, coniferous forests, broad-leaved forests, mining sites, grasslands, industrial lands, shrubs, residential land, bare soil, sandy land, lake ponds, salt marshes and gardens, respectively. The socio-economic data was acquired from the Statistical Bulletin of the National Economic and Social Development of Liaoning Province in 2006, 2011 and 2016 (http://www.ln.stats.gov.cn/tjsj/tjgb/ndtjgb/). According to Gong et al.'s principle of selecting socio-economic factors(Gong et al.,2013), we used four types of major social and economic factors, namely, population, economics, social activities, and education(Xu et al.,2014). Based on the socio-economic development characteristics and data availability of the central and southern Liaoning urban agglomerations, 11 county-scale impact factors were selected: population factors (total population and population density), economic development factors (GDP, per capita GDP, industrial total output value, foreign investment and total fiscal revenue, social activity factors (fixed asset investment, total retail sales of consumer goods, and employment numbers) and education factors (number of teachers).

3.2 Ecosystem Service Estimation

3.2.1 Data Standardization: Burkhard et al.(2009) has indicated that the multiple ecosystem service can be described by the matrix of ecosystem services, which assess the ability of various land cover categories to provide ecosystem services. Each land cover type has its corresponding supply and demand value of ecosystem service, with the scores of 0-5 for ecosystem service. In this study, multiple ecosystem service in the central and southern Liaoning urban agglomerations was evaluated at county scale. Due to the different area of each study unit (county), the order of magnitude of above indicators is different. In order to eliminate this effect, the total sum of services for each ecosystem needs to be standardized(Koschke et al.,2012). The formula is as follows:

$$Is = \frac{I - I_{min}}{I_{max} - I_{min}} \tag{1}$$

where Is is the standardized value of county-level ecosystem services, with values ranging from 0-1; I is the sum of county-level single ecosystem services; and Imin and Imax represents the minimum and maximum values of a single ecosystem service, respectively.

3.2.2 IMES Model: According to the multiple ecosystem services comprehensive index (IMES) model proposed by Zhang et al.(2017), each standardized county-level Is is summed up, and the integrative index of multiple-ecosystem services (IMES) is obtained by the following equation:

$$IMES = \sum_{i=1}^{n} Is(i) \tag{2}$$

where n represents the number of ecosystem services, with a total of 22. In equations (1) and (2), the calculated IMES values based on the matrix of supply services and demand services are defined as the multiple ecosystem service supply index ($IMES_s$) and the demand index ($IMES_d$), respectively. Thus, the balance of ecosystem service supply and demand in the study area can be calculated as follows:

$$IMES_b = IMES_s - IMES_d \tag{3}$$

$IMES_b$ <0 shows that the demand for ecosystem services significantly exceeds the supply (i.e., undersupply); $IMES_b$ =0 indicates the balance of supply and demand; $IMES_b$ >0 shows that the supply is higher than the demand (i.e., oversupply)

3.3 Statistical Analysis

With Spss 22.0 software (SPSS Inc, 2013), the correlation coefficients between 11 social and economic influencing factors were calculated. The multiple regression analysis was performed between the social and economic factors and $IMES_s$, $IMES_d$, and $IMES_b$ for the year of 2005, 2010, and 2015, respectively. The stepwise regression analysis was used to determine the socio-economic factors influencing the supply, demand, and balance of ecosystem services in the region for each study period.

4. RESULTS

4.1 Spatial-temporal Pattern of Multiple-ecosystem Services

4.1.1 Changes in Ecosystem Services Supply: During the past ten years, the supply of multiple ecosystems service in the central and southern Liaoning urban agglomerations showed a trend of decreasing first and then increasing. Figure 2 shows the spatial distribution of ecosystem services supply and demand in the study area. $IMES_s$ and $IMES_d$ were classified into five levels by natural crack point method. In 2005, the average value of $IMES_s$ in the study area was 10.59, of which Yingkou municipal district had the lowest ecosystem service supply index (2.73), while the highest $IMES_s$ (16.81) was observed in Changhai County. Overall, the supply of ecosystem services in the southern part was better than in the north (Figure 2A).

In 2010, the supply of ecosystem services decreased slightly. The average $IMES_s$ value was 10.53. The value of ecosystem services supply index in Yingkou City and Changhai County was the lowest (2.16) and the highest (16.85) in the whole area, respectively (Figure 2B). From 2005-2010, the supply of ecosystem services declined in 10 counties, among them the $IMES_s$ in Tieling's municipal district decreased by 1.32 with the most obvious decrease. The value of $IMES_s$ in Anshan municipal district increased by 0.64 with most obvious increase in the supply of ecosystem services.. In 2015, $IMES_s$ increased slightly and the average value reached 10.90. $IMES_s$ value of Fushun County was 17.93 with the best level of ecosystem service supply. By contrast, Yingkou city had the lowest value in the region ($IMES_s$ =2.49). The supply of ecosystem services tended to be equal in the southern and northern regions.

During 2010-2015, ecosystem services supply in 6 administrative units declined. The $IMES_s$ value of Dandong reduced by 7.89, suggesting the most significantly decreasing in the supply of ecological services. In Liaoyang, ecosystem service supply tended to improve, because the value of $IMES_s$ increased by 4.03.

4.1.2 Ecosystem Services Demand Variation: In 2005, the average value of $IMES_d$ in the study area was 8.49. The ecosystem services demand in Fushun was the least ($IMES_d$ =2.59), whereas the maximum service demand was found in Yingkou municipal district with $IMES_d$ of 14.59. The ecological service demand in the central areas was greater than that in other regions.

In 2010, the regional average $IMES_d$ fell to 8.24, and the ecosystem service demand in the central region was more than that in other areas. The minimum value ($IMES_d$ =2.67) still occurred in Fushun County. Dashiqiao had the highest demand for multi ecosystem services with $IMES_d$ of 14.16. In 2015, the ecosystem service demand of the southern and northern region in this urban agglomeration tended to be equal. The regional average value of $IMES_d$ was 5.24 in 2015, and the demand of Fushun was the least ($IMES_d$ =0.86). The demand for ecosystem services in Yingkou was the highest and its $IMES_d$ value was 21.76.

From 2005-2010, the demand on multiple ecosystem services in 12 counties decreased, among which the demand of Yingkou dropped the most, because the $IMES_d$ value reduced by 1.96. In Anshan, the value of $IMES_d$ increased by 0.99, where the demand for ecological services increased most. For the period of 2010-2015, the average $IMES_d$ of this urban agglomeration decreased significantly. The value of $IMES_d$ in Dashiqiao reduced by 7.98, indicating the demand for ecological service declined most obviously. In Yingkou, the value of $IMES_d$ increased by 9.13, suggesting the growing demand for ecological services.

4.1.3 Changes in Ecosystem Services Balance: In 2005, the average value of $IMES_b$ was 2.10, and there were 8 counties with $IMES_b$ <0 (Figure 2). The $IMES_b$ of Yingkou (-11.87) was the lowest in the region, while the ecosystem services of Changhai County reached the highest level of coordination of supply and demand in the region ($IMES_b$ =12.17). In 2010, the regional average $IMES_b$ value was 2.28, and the numbers of regions with $IMES_b$ <0 reduced to 7. The $IMES_b$ in Yingkou municipal district and Changhai County were -10.47 and 12.13, respectively. These two regions were still the areas with the highest level of ecological service supply deficit and supply-demand balance. In 2015, the average value of $IMES_b$ in this urban agglomeration rose to 5.65. The average value of $IMES_b$ < 0 was only found in Yingkou municipal district and Shenyang municipal district. The lowest level of ecosystem service supply and demand balance ($IMES_b$ = -19.28) was observed in Yingkou municipal district, whereas $IMES_b$ (17.07) in Changhai was the highest in the study area.

From 2005-2010, the balance of ecological services in 11 counties and cities declined, among them the most obvious reduction was found in Dashiqiao whose $IMES_b$ value reduced by 1.26. The value of $IMES_b$ in Anshan increased by 2.04, indicating the most obviously increased balance of ecological services. From 2010-2015, the balance index of ecosystem services in Yingkou declined most obviously, whose $IMES_b$ value reduced by 8.81. Only two administrative units had an increased balance in multiple ecosystem services.

4.2 Relationships Between Ecosystem Services and Socioeconomic Factors

According to the statistic analysis, $IMES_s$ and GDP in the urban agglomeration showed no significantly negative correlation in 2005. In 2010, with the decrease of population density, GDP and foreign investment, $IMES_s$ value showed an increasing state. There was a positive correlation between the value of per capita GDP and $IMES_s$. In 2015, $IMES_s$ was negatively correlated with population density and industrial output value, but had a positive correlation with the number of teachers.

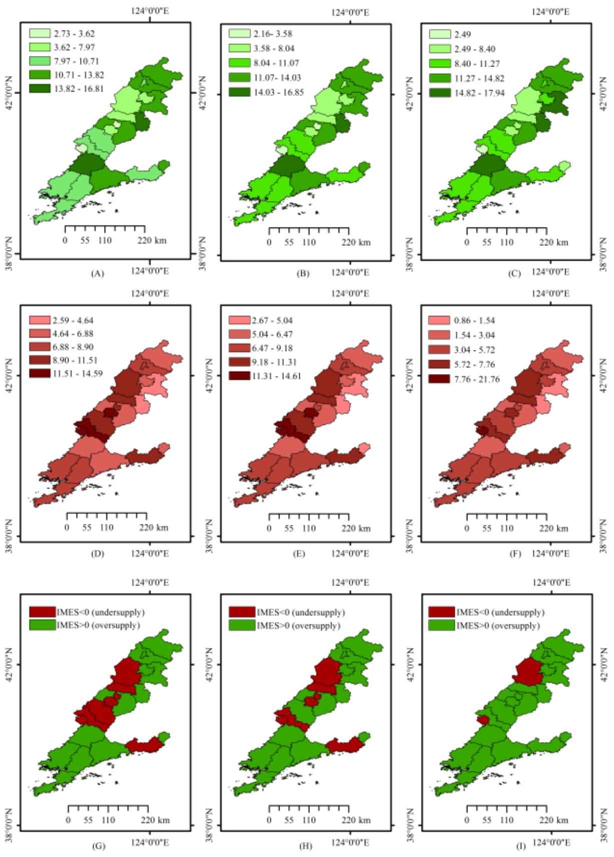

Figure 2. Ecosystem services supply(A:2005,B:2010,C:2015), demand(D:2005,E:2010,F:2015) and balance(G:2005,H:2010,I:2015) in the central and southern Liaoning urban agglomerations

In 2005, there was a significant positive correlation between $IMES_d$ and GDP. With the increase of GDP, the $IMES_d$ value also increased significantly, indicating that the demand of ecosystem services increased. In 2010, with population density, GDP and foreign investment growing, $IMES_d$ increased. We found that there was a significantly positive correlation between $IMES_d$ and population density and foreign investment in 2015. When population density and foreign investment increased, the $IMES_d$ value also increased significantly.

Regarding the contribution of socio-economic factors to ecosystem services demand, we found that the $IMES_b$ value decreased significantly with the increase of GDP in 2005. In 2010, due to the increase of population density, GDP and foreign investment, $IMES_b$ decreased, indicating the balance of ecosystem services weakened. The per capita GDP was positively related to $IMES_b$. In 2015, $IMES_b$ was negatively related to population density, industrial output value and foreign investment.

The stepwise regression procedure was performed using socio-economic factors as independents and ecosystem services supply, demand and balance as dependents. The models for supply, demand, and balance of ecosystem services in the central and southern Liaoning urban agglomerations were determined respectively:

$$Y_s = -0.004X_1 + 13.33 \tag{4}$$

$$Y_d = 0.003X_1 + 5.609 \tag{5}$$

$$Y_b = -0.006X_1 + 7.72 \tag{6}$$

Among them, Y_s, Y_d, and Y_b represented $IMES_s$, $IMES_d$, and $IMES_b$, respectively, and X_1 was population density. The significance test of the above three models was less than 0.05. In the past 10 years, the supply, demand, and balance of ecosystem services in central and southern Liaoning urban agglomerations were all related to the population density. The population density was lower, the larger the $IMES_s$ and $IMES_b$ values was. The higher the population density was, the higher the $IMES_d$ value might be.

5. DISCUSSION

5.1 Changes in the Supply and Demand Pattern of Ecosystem Services

In the past 10 years, the supply of ecosystem services in the central and southern Liaoning urban agglomerations had been increasing, while the demand had been decreasing. Most of the regions with large supply of ecosystem services were small cities with less development, and the regions with much demand on ecosystem services were more developed cities. The regions of excessive ecosystem services supply were agricultural counties with the lower level of industrialization, relatively slow development of social economic levels and, sparsely populated. By contrast, In cities with a high degree of industrialization and rapid socio-economic development and dense population, the supply of multiple ecosystem services was insufficient. The results of this study are consistent with the research on the supply and demand pattern of ecosystem services in the Yangtze River Basin, China. It is also similar to the results of Peng et al.’s (2017) study on ecosystem services supply and demand in Guangdong province, China.

5.2 Socioeconomic Driving Forces of Ecosystem Services Change

In this study, we found that the change of ecosystem service supply ($IMES_s$) in the central and southern Liaoning urban agglomerations was negatively correlated with GDP in 2005. In 2010, there was a negative correlation with population density, GDP and foreign investment. The value of per capita GDP was positively correlated with the value of $IMES_s$, which was not consistent with the conclusion of Zhang et al.(2017). The possible reason is that the higher the per capita GDP, the less people who engage in primary production activities. The lower demand for agricultural production and forest resource utilization is. Therefore, the supply of ecosystem services in these areas may be enhanced, and the greater the $IMES_s$ value is. In 2015, $IMES_s$ had a negative correlation with population density and total industrial output value, and had a positive correlation with the number of teachers. This may be because that the more teachers and the higher education level of the people, the better the consciousness of the ecological, protection and the larger the $IMES_s$. In the areas with the lower population density usually provides more ecosystem services. Rodr ǵuez-Loinaz et al. (2015) also found there were more ecosystem services in areas with lower population density (e.g. rural region).

With the increase of population density, foreign investment and GDP, the demand for ecosystem services increased and the

$IMES_d$ increased significantly. However, there had no significant correlation between $IMES_d$ and GDP after 2010, which might be related to the slow growth of GDP in the region.. Since 2010, foreign investment began to have significant relationship with $IMES_d$. Because of the global economic crisis in 2008 and the transformed economy development model, foreign investment had become an important indicator to measure the development of the region. Similar to the demand for ecosystem services, $IMES_b$ has had no significant relationship with GDP since 2010. With the slowdown in GDP growth in the region, social and economic development has also been slowing. Foreign investment and population density were significantly related to $IMES_b$ in 2010. Gross industrial output value had significantly impact on $IMES_b$ in 2015, indicating that in the regions where the densely populated, good foreign investment environment, and high level of industrialization, $IMES_b$ values were low and demand of ecosystem services was less than the supply.

The study has some drawbacks. Firstly, due to the incomplete economic factors in some counties, the lack of data sets may cause incomplete results. Secondly, the relatively simple statistic methods probably fail to carry out a deeper analysis of the ecosystem services and socio-economic factors in the region.

6. CONCLUSIONS

Based on Landsat ETM+ and OLI remote sensing imagery, land use/cover type information was extracted. An adjusted ecosystem service matrix was established, and the integrative index of multiple-ecosystem services (IMES) were calculated to quantitatively analyze the dynamics of supply and demand of ecosystem services in the central and southern Liaoning urban agglomerations from 2005 to 2015. The study primarily identified major socio-economic drivers of changes in multiple ecosystem services. The following conclusions have been obtained:

Average $IMES_s$ values in central and southern Liaoning urban agglomerations were 10.59 in 2005, 10.53 in 2010, and 10.90 in 2015, respectively. The ecosystem service supply showed a trend of decreasing first and then increasing, while the ecosystem service demand tended to decrease. The average $IMES_d$ was 8.49 (2005), 8.24 (2010), 5.24 (2015), respectively. During the past ten years, the regional average $IMES_b$ increased from 2.10 to 5.65, and the balance of ecosystem services increased significantly. The number of administrative units for the supply of ecosystem services was reduced from 8 in 2005 to 2 in 2015, indicating that the overall eco-environment in the central and southern Liaoning urban agglomerations has improved during the past 10 years.

In terms of spatial distribution, the supply of ecosystem services in the southern region was greater than in the north. From 2005 to 2015, the supply of ecosystem services in 14 administrative units improved, and most of them were located in the south. The demand for ecological services in the central region was greater than in other regions. The distribution of administrative units of $IMES_b < 0$ becomes centralized spatially.

Based on the stepwise regression analysis method, the supply, demand and balance model of ecosystem services were established to explain the driving forces. In the past 10 years, ecosystem services supply, demand, and balance were all related to the population density in this urban agglomeration. In regions with lower population density, the larger values the $IMES_s$ and $IMES_b$ were observed. Higher population density might cause higher $IMES_d$ value.

There are significant differences in the driver forces of multi-ecosystem services supply, demand, and balance changes. The results of this paper showed that $IMES_s$ values were usually negatively correlated with GDP, population density, foreign investment and total industrial output value. However, some social-economic factors had positive effects on $IMES_s$, such as per capita GDP and number of teachers. Similar results were also found in the analysis of $IMES_b$. $IMES_d$ had a positive correlation with GDP, population density and foreign investment. After establishing the ecosystem service model, it was found that the population density had the greatest impact on the balance of ecosystem services. Therefore, policy makers should consider the role of socio-economic factors that affect multiple ecosystem services in these regions when doing development planning. It may help to increase social and economic levels, improve the ecological environment, and reduce the differences between cities.

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REFERENCES

Burkhard, B., Kroll, F., Müller, F. and Windhorst, W., 2009. Landscapes' capacities to provide ecosystem services - a concept for land-cover based assessments. *Landscape Online*,15(1), pp. 1-12.

Burkhard, B., Kroll, F., Nedkov, S. and Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. *Ecological Indicators*, 21(3), pp. 17-29.

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. and van den Belt, M., 1997. The value of the world's ecosystem services and natural capita. *Nature*, 387(1), pp.253-260.

Gong, C.F., Yu, S.X., Joesting, H. and Chen, J.Q., 2013. Determining socioeconomic drivers of urban forest fragmentation with historical remote sensing images. *Landscape & Urban Planning*, 117(9), pp.57-65.

Han, J.R., 2013. The impact of urban sprawl on carbon stocks based on the InVEST model, Northeast Normal University, China

Koschke, L., Fürst, C., Frank, S., and Makeschin, F., 2012. A multi-criteria approach for an integrated land-cover-based assessment of ecosystem services provision to support landscape planning. *Ecological Indicators*, 21(21),pp.54-66.

Liu, J.G.; Li, S.X.; Ouyang, Z.Y.; Tam, C.; and Chen, X.D. (2008): Ecological and socioeconomic effects of China’s policies for ecosystem services In: *Proceedings of the National Academy of Sciences*, 105(28), pp.9477-9482.

Ma, L., Liu, H., Peng, J., and Wu, J.S., 2017. A review of ecosystem services supply and demand. *Acta Geographica Sinica*,72(7), pp.1277-1289.

Peng, J. Yang, P., Xie,P., and Liu,Y.X., 2017. Zoning for the construction of green space ecological networks in Guangdong Province based on the supply and demand of ecosystem services.. *Acta Ecologica Sinica* ,37(13), pp. 4562-4572.

Rodriguez-Loinaz, G., Alday, J. G., and Onaindia, M., 2015. Multiple ecosystem services landscape index: a tool for multifunctional landscapes conservation. *Journal of Environmental Management*, 147, pp.152-163.

SPSS Inc, 2013. IBM SPSS Software, Version 22. https://www.ibm.com/analytics/data-science/predictive-analytics/spss-statistical-software (1 June 2017).

Statistics Bureau of Liaoning Province. 2017. Statistical Bulletin of the National Economic and Social Development of Liaoning Province, Liaoning Statistical Information Net. http://www.ln.stats.gov.cn/tjsj/tjgb/ndtjgb/ (1 June 2017).

Swetnam, R. D., Fisher, B., Mbilinyi, B. P., Munishi, P. K., Willcock, S., Ricketts, T., Mwakalila, S., Balmford, A., Burgess, N. D., Marshall, A. R., and Lewis, S.L., 2011. Mapping socio-economic scenarios of land cover change: a GIS method to enable ecosystem service modelling. *Journal of Environmental Management*, 92(3), pp.563-574.

U.S. Geological Survey (USGS),2017. USGS Global Visualization Viewer (GloVis). https://glovis.usgs.gov/ (1 June 2017).

Xu, J., Grumbine, R. E., and Beckschäfer, P., 2014. Landscape transformation through the use of ecological and socioeconomic indicators in Xishuangbanna, southwest china, Mekong Region. *Ecological Indicators*, 36(1), pp.749-756.

Zhang, Z.M., Gao,J.F., Fan, X.Y., Lan , Y., and Zhao, M.S., 2017. Response of ecosystem services to socioeconomic development in the Yangtze River Basin, China. *Ecological Indicators*, 72(1), pp.481-493.