Boundary Setting for Ecosystem Services by Factor Analysis

A Case Study in Seochon, South Korea

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Abstract: Ecosystem service assessment maps are an important form of data, showing the flow and characteristics of ecosystem services. However, there has been a lack of research on the spatial boundaries of synergetic and trade-off relationships among different types of ecosystem services based on the microscopic characteristics of ecosystem maps. Therefore, the boundaries of ecosystems were identified in this study using factor analysis of indicators in ecosystem service maps. Ecosystems were mapped for each indicator in each cell, and then factor analysis was used to combine all indicators into one map. Analysis of Seochon in central South Korea shows the boundaries of two ecosystem types: a mountainous region with abundant underground water and carbon stocks that lack rice paddies, and flatlands with high crop production and a lack of scenic views. The spatial types of ecosystems in which synergy and trade-offs occur were identified by indicator, and these can be used as evidentiary material for spatial planning in order to maximize the function of each ecosystem service.

1. INTRODUCTION

Since the concept of “ecosystem services” as beneficial services provided by nature ([Millennium Ecosystem Assessment \(MEA\), 2005](#); [Mouchet et al., 2017](#); [The Economics of Ecosystems and Biodiversity \(TEEB\), 2010](#)) was introduced, it has been used as a decision-making tool for sustainable development and environmental planning ([Fisher & Turner, 2008](#); [Koschke et al., 2012](#); [Martinez-Harms et al., 2015](#); [Tallis et al., 2008](#)). Ecosystem service assessment maps provide useful information by analyzing the flow and context of indicators in an ecosystem ([Burkhard & Maes, 2017](#); [Burkhard, Petrosillo, & Costanza, 2010](#); [Egoh et al., 2008](#); [Maes et al., 2012](#); [Martínez-Harms & Balvanera, 2012](#); [Naidoo et al., 2008](#); [Sherrouse, Clement, & Semmens, 2011](#); [Tallis & Polasky, 2009](#)), and therefore are often the target of research. Early ecosystem service assessment maps were created at the level of map construction by indicator ([Costanza et al., 1997](#); [Luck, Chan, & Klien, 2012](#); [Nahuelhual et al., 2013](#); [Pleninger et al., 2013](#); [Schröter & Remme, 2016](#); [Tieskens et al., 2014](#)) or simple summations of assessment maps were utilized to convert indicators into economic values ([Häyhä et al., 2015](#);

[Sherrouse, Clement, & Semmens, 2011](#); [Swetnam et al., 2011](#); [Troy & Wilson, 2006](#)).

One of the uses of ecosystem service maps is the identification of spatial boundaries ([Bryce & Clarke, 1996](#); [Strayer et al., 2003](#)) in which the synergy or trade-off between indicators occur ([Haase et al., 2012](#); [Hicks, Graham, & Cinner, 2013](#); [Howe et al., 2014](#); [Jia et al., 2014](#); [Jopke et al., 2015](#); [King et al., 2015](#); [Qin, Li, & Yang, 2015](#); [Swallow et al., 2009](#); [Tomscha & Gergel, 2016](#)). By analyzing the correlations among ecosystem service types, it is possible to identify the subcategories that have mutually beneficial relationships. Expanding the areas with such synergistic relationships will help to improve ecosystem services ([Cai et al., 2017](#); [Cimon-Morin, Darveau, & Poulin, 2013](#); [Raudsepp-Hearne, C. Peterson, & Bennett, 2010](#)). Meanwhile, if there are any ecosystem service subcategories that are negatively correlated, plans can be made to reduce the areas showing these trade-off relationships, or to select the subcategory that offers greater benefits. Spatial planning that reduces the conflict between ecosystem services and increases the synergy of them allows for the value of ecosystem services to be maximized ([Bennett, Peterson, & Gordon, 2009](#); [Elmqvist et al., 2013](#); [Kim, I. & Arnhold, 2018](#); [Kim, I. et al., 2017](#); [Li & Wang, 2018](#); [Lin et al., 2018](#); [White, Halpern, & Kappel, 2012](#)). Therefore, several researchers have attempted to create ecosystem service maps and identify correlations, but their studies have focused only on cultural services ([Plieninger et al., 2013](#)) or were limited to administrative districts ([Haines-Young, Potschin, & Kienast, 2012](#); [Hamann, Biggs, & Reyers, 2015](#); [Jopke et al., 2015](#); [Oakley et al., 2018](#); [Queiroz et al., 2015](#); [Raudsepp-Hearne, C. Peterson, & Bennett, 2010](#); [Schulp et al., 2014](#); [Yang et al., 2015](#)). Such studies are limited in their ability to identify spatial boundaries based on the microscopic flow of overall ecosystem services in order to create a useful foundation for local policymaking.

It is possible to base ecosystem service maps on more detailed analytical units (relative to administrative districts) in order to identify types of ecosystem services based on microscopic ecological flows. This can create a more useful tool for local planning ([Grêt-Regamey et al., 2015](#); [Raudsepp-Hearne, Ciara & Peterson, 2016](#)). A cell-based ecosystem service map is not influenced by the form or size of each administrative area, and it therefore aids in our understanding of the continuity of local ecosystem services ([Emmett et al., 2016](#)). Although different cell sizes and forms produce dissimilar results, it has been observed that the trends of synergy and trade-offs among ecosystem services remain unchanged ([Dittrich et al., 2017](#); [Turner et al., 2014](#)). Additionally, a cell-based ecosystem service map is useful for related analyses with other spatial information and consistent assessments because of the equally spaced inspection. Although it is not convenient for policymaking based on administrative areas, it is more beneficial for making micro environmental spatial plans. Therefore, in this study, a cell-based ecosystem service map was constructed using different indicators. Factor analysis based on the correlation between maps for each indicator was conducted to identify the spatial types and boundaries of ecosystem services in the study region.

2. MATERIALS AND METHODS

Seocheon in South Korea was selected as the study area as it is a region with various coastal and inland ecosystems (Figure 1) (([Lee et al., 2017](#); [Lee, Kim, & Kwon, 2017](#)). Seocheon County includes areas designated as Ramsar Wetlands of International Importance and provides habitats for numerous migratory birds and wetland organisms. The county is a repository for a myriad of migratory birds and wetland wildlife. The wetland shores provide habitats for diverse fishery resources, such as seaweed (green laver and algae), clams (Manila clam, surf clam, and Gould's razor shell), and crustaceans (prawn, swimming crab, mantis shrimp, Japanese mud shrimp, and Japanese swimming crab). Additionally, tidal mudflats serve as an intermediate stopover point, with ample food for migratory birds, including spoonbills, black-faced spoonbills, Chinese egrets, shorebirds, Chinese goose, bean goose, and others. Furthermore, the inland ecosystems form part of the estuary of the Keum River ([Kim, T. I., Choi, & Lee, 2006](#); [Yoon et al., 2017](#)), an agricultural area with active rice farming (Figure 2). Both the National Institute of Ecology¹ and the Marine Biodiversity Institute of Korea² are located in Seocheon, where research is conducted on both the preservation and utilization of valuable ecological resources.

Figure 1. Study area showing different ecosystems present and the location in the wider region

Both ArcGIS and InVEST³ were used to produce a cell-based ecosystem service map. First, rice paddies, dry field farming, and sites under sheltered cultivation were extracted from land cover maps from the Ministry of Environment in South Korea and mapped as provisioning services (Table 1). The InVEST program was used to map regulating services, including underground water storage (Table 2; Figure 2) and the extent of erosion (Table 3).

¹ The National Institute of Ecology is a place for ecological research, exhibition and education, where the five primary classifications of climate (tropical, desert, Mediterranean, temperate, and polar) and around 4,500 animal and plant species inhabiting the climatic areas, can be explored and experienced.

² The Marine Biodiversity Institute of Korea was established for the sustainable use and comprehensive management of marine bioresources. The institute has facilities for research and education, as well as exhibiting marine biodiversity, future marine industries, and ocean-themed videos.

³ InVEST is an open-source software program that allows the public to evaluate ecosystem services. It evaluates the current state and has functions for forecasting changed states by possible scenarios (Tallis, 2011).

Table 1. Data sources of provisioning services

Division			Classification by ground coverage
Food crops	Rice	-	Rice paddy
	Barley	Hulled barley, naked barley, malting barley, wheat, rye	
	Miscellaneous grain crops	Corn, buckwheat, etc.	
	Pulses	Soybean, red bean, etc.	
	Root and tuber crops	Sweet potato, potato	
Vegetables	Leaf vegetables	Chinese cabbage, cabbage, spinach, lettuce, wormwood, brown mustard, dropwort, leek	Dry field
	Root and bulb vegetables	Radish, carrot, taro, burdock, lotus root	
	Condiment vegetables	Chili pepper, Welsh onion, onion, ginger, garlic, Western herbs and vegetables such as rosemary, celery, etc.	
Fruits	Fruit vegetables	Watermelon, oriental melon, cucumber, pumpkin, tomato, strawberry, melon, green chili pepper, eggplant, paprika	Cultivation under structure
	Apple, pear, peach, grape, mandarin, plum, Japanese apricot, citron, kiwifruit, fig, persimmon		Orchard
Industrial crops	Sesame, <i>Perilla</i> , peanut		Field

Table 2. Data sources of water yield in regulatory services

Division	Data	Source
Precipitation	Average annual, monthly precipitation (1960–1990)	WorldClim ¹
Average reference evapotranspiration	Global potential evapotranspiration (PET) - annual, monthly (1950–2000)	CGIAR-CSI ²
Root restricting layer depth	Stock map (1:5000)	Korea Forest Service Canadell et al. (1996)
Plant available water fraction	Forest soil map (1:5000)	Korea Forest Service TaeHoon and YoungKi (2003)
Land use/land cover	Stock map (1:5000)	Korea Forest Service
Watersheds	Watersheds map	WAMIS ³
Biophysical table	Vegetation factor	InVEST
Z-value	30	Redhead et al. (2016)

¹ WorldClim: Global climate database² CGIAR-CSI: CGIAR-Consortium for Spatial Information³ WAMIS: Water Resources Management Information System in Korea

Figure 2. Process of mapping the assessed water yield (left) and the output water yield (right)

Table 3. Data sources of erosion in regulating services

Division	Data	Source
Rainfall erodibility factor (R)	Monthly raster data	National Institute for Disaster Prevention
Soil erodibility factor (K)	Detailed soil map (1:25000)	Space data, National Academy of Agricultural Science; Property data, Ministry of Environment
Slope length and steepness factor (LS)	Digital map (1:5000)	National Geographic Information Institute
Cover management factor (C)	Subdivided land cover map	Space data, Ministry of Environment; Property data, Ministry of Environment; Natural Capital Project

Carbon absorption was mapped using a statistical value provided by the Korean Forest Service (Table 4), and InVEST was used to calculate recreation and scenic quality values for cultural services. The number of geo-tagged photographs provided on Flickr per month was used to calculate recreation, and an overlay value of scenic quality, excluding population values, was calculated. Population data were only available at the administrative district level, which is of coarser resolution than the cell size used in map analyses. Therefore, population was excluded. The ecosystem service maps constructed using these methods were unified to identical cell scales (Table 5).

Table 4. Data sources of carbon absorption in regulating services

Division	Data (source)	Output
Growing stock per unit area according to forest floor and age class		Annual CO ₂ absorption (standing timber) and carbon storage (standing timber/litter layer/forest soil) estimates
Conversion factors of each species (BWD ¹ , BEF ² , R, CF ³)	Stock map (Korea Forest Service) and sub-divided land cover map (Ministry of Environment)	
Annual CO ₂ absorption amount of each of the main species per hectare		
Carbon amount per unit area of litter layer		
Carbon storage amount per unit area of forest soil		

¹ BWD: Basic Wood Density

² BEF: Biomass Expansion Factor

³ CF: Carbon Fraction

Table 5. Data sources of water yield in regulating services

Division	Data	Source
Recreation	Geo-tagged photo user-day calculations from 2005–2014	Flickr (https://www.flickr.com/)
Scenic Quality	Digital elevation model	National Geographic Information Institute
	Features impacting scenic quality (tourism point)	Tourism Knowledge Information System

A summary of the entire assessment and mapping process is shown in Table 6. After a layer was created for each indicator, a correlation analysis between indicator layers was conducted, followed by principal component analysis (PCA), with the aim of identifying correlations between indicators. Finally, extracted factors were mapped by their Z-value to interpret their spatial significance.

Table 6. Total ecosystem service indicators for cell-based maps

Services	Item	Indicator	Scope	Unit
Provisioning services	Rice production			
	Farm production	Production area	Total map area	ha
	Polytunnel production			
Regulating services	Water	Water storage	Forest	t/yr
	Carbon	Amount of net CO ₂ absorption/year	Forest; tree stands	t
	Erosion	Soil erosion of land reserves	Forest	t/yr
Cultural services	Scenic quality	Scenic overlay	Total map area	No. of overlays
	Recreation	Geo-tagged photos from Flickr	Total map area	Mean no. of photos per month

3. RESULTS

3.1 Ecosystem Service Mapping by Indicator

For factor analysis, mapped values for each indicator were unified at 250 × 250 mm, which is the default unit in ArcGIS. The zonal statistics function of ArcGIS was used. Maps of provisioning services showed that paddy fields were concentrated in flatlands, farms were concentrated in regions between paddy fields and mountains, and sites of sheltered cultivation and orchards were scattered across certain areas (Figure 3). Overall, the value of provisioning services was higher in regions with greater flatlands, and lower in mountainous regions.

Figure 3. Mapped provisioning ecosystem services (ha)

Maps of regulating services showed that values were higher in regions with groundwater and carbon storage (Figure 4). In contrast, erosion was present across the Seochon region. Viewshed values for scenic quality ([Griffin et al., 2015](#)), a cultural service item that can be analyzed at the cell level, were high at sites where observers could look down onto flatlands (Figure 5). Recreation values were scattered across coastal regions, in the city of Seochon, and in the reed recreational park ([Keeler et al., 2015](#); [Wood et al., 2013](#)).

Figure 4. Mapped regulating ecosystem services (t)

Figure 5. Mapped cultural ecosystem services

3.2 Factor Analysis

The analyses of correlations between factors revealed a high positive correlation between carbon storage and the amount of underground water storage. However, these two indicators were both strongly negatively correlated with rice farming (Table 2). Factor analysis resulted in the extraction of two factors (Table 8 and 9), with a Kaiser-Meyer-Olkin (KMO) sampling adequacy value of 0.624 (Equation 1) and a Bartlett's test significance level of 0.000:

$$KMO = \frac{\sum_i \sum_{j \neq i} r_{ij}^2}{\sum_i \sum_{j \neq i} r_{ij}^2 + \sum_i \sum_{j \neq i} a_{ij}^2}, \quad (1)$$

where r is the elements of the correlation matrix, and a is the elements of the partial correlation matrix. The KMO is a metric of how suitable the data are for factor analysis, where values from 0.90 to 1.00 indicate that the sampling is highly suitable, values from 0.80 to 0.89 indicate that the sampling is very suitable, and values from 0.70 to 0.79 indicate that the sampling is acceptable. When KMO values are less than 0.69, the data may be considered somewhat suitable to completely unacceptable ([Kaiser, 1974](#)).

Table 8. Total variance explained by each component, extracted by principal component analysis

C ¹	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	Variance explained (%)	Cumulative variance (%)	Total	Variance explained (%)	Cumulative variance (%)	Total	Variance explained (%)	Cumulative variance (%)
1	2.509	27.881	27.881	2.509	27.881	27.881	2.509	27.876	27.876
2	1.391	15.459	43.341	1.391	15.459	43.341	1.392	15.465	43.341
3	1.000	11.111	54.451						
4	0.993	11.029	65.481						
5	0.966	10.730	76.211						
6	0.860	9.559	85.769						
7	0.794	8.818	94.587						
8	0.413	4.591	99.178						
9	0.074	0.822	100.000						

¹C: Component

Table 9. Varimax rotated principal components matrix rotated with Kaiser normalization (rotation converged after three iterations). The bold number represents the highest loading of the two factors

Indicators	Principle Component	
	1	2
Underground water	0.941*	-0.084
Carbon	0.927*	-0.087
Rice paddy	-0.741	-0.181
Orchard	0.164	0.034
Farm	-0.158	0.714*
View	-0.351	-0.542
Structure	-0.181	0.525*
Erosion	0.066	0.503*
Recreation	-0.052	-0.098

The analyses showed that underground water and carbon storage clustered positively in Principle Component 1, while rice paddy production clustered negatively with these indicators. In Principle Component 2, dry field farming, sites of sheltered cultivation and soil erosion clustered positively, while regions with high scenic value clustered negatively (Table 4). This signifies that mountainous regions abundant in underground water and carbon storage where rice cultivation is difficult were extracted as Principle Component 1, and productive flatlands suffering from soil loss due to intensive agriculture were extracted as Principle Component 2 (Figure 6).

Figure 6. Mapping factors identified in principal component analysis boundary setting for ecosystem services

The analysis of ecosystem service maps of Seochon for different indicators using factor analysis resulted in the extraction of two ecosystem types and their boundaries. The first type was ecosystems centered around mountains. These areas are abundant in underground water and carbon storage, but are in locations where it is extremely difficult to farm rice. Spatial planning is required to allow enhancement of regulating ecosystem services in these areas. The second type was ecosystems centered around flatlands. These areas are abundant in provisioning services but suffer from greater erosion and a lack of scenic qualities. Provisioning services should be maximized in these areas.

Since the Seochon region includes various forms of ecosystems, such as coastal and inland habitats, urban and rural settings, and agricultural land and forests, planning ecosystem services requires consideration of many complicated aspects. Based on the results of this study, it is recommended that the Seochon local government increase underground water and carbon storage in mountain areas. Furthermore, the arrangement of farms and polytunnel production in agriculture areas is useful for maximizing ecosystem services. Through the factor analysis of cell-based ecosystem service maps showing different indicators, two main types of ecosystems, mountains and flatlands, were extracted. Synergetic (e.g., underground water and carbon; farms, CO₂, and erosion) and trade-off (e.g., rice paddies vs. underground water and carbon; scenic quality vs. farms, CO₂, and erosion) relationships

between the two ecosystem service types (mountains and agriculture) and their boundaries were identified, providing one method of finding the main ecosystems and boundaries that are often discussed theoretically ([Banks-Leite & Ewers, 2009](#); [Prieto-Torres & Rojas-Soto, 2016](#); [Saunders & Briggs, 2002](#)); beyond administrative districts ([Haines-Young, Potschin, & Kienast, 2012](#); [Hamann, Biggs, & Reyers, 2015](#); [Jopke et al., 2015](#); [Oakley et al., 2018](#); [Queiroz et al., 2015](#); [Raudsepp-Hearne, C, Peterson, & Bennett, 2010](#); [Schulp et al., 2014](#)). These results are consistent with previous studies that have grouped items and shown ecosystem service synergies and trade-offs, and examined how the corresponding areas were distributed in space ([Früh-Müller et al., 2016](#); [Qiu & Turner, 2013](#)). However, the results of this study go one step further by showing what forms may arise in boundary areas.

This study has limitations in terms of the data used, which was focused on inland habitats, and did not include sufficient data from coastal areas. Additionally, the results may differ slightly depending on which lines are selected for factor loading in factor analyses based on the positive and negative correlations in the data. Nevertheless, the findings have significance for spatially identifying types of ecosystem services and verifying their characteristics. Future research should aim to construct more detailed and comprehensive maps of ecosystem service data to allow the identification of ecosystem types across larger areas, thereby facilitating the maximization of ecosystem services according to the characteristics of the respective ecosystem types.

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