Boundary Setting for Ecosystem Services by Factor Analysis
A Case Study in Seocheon, South Korea

Jae-hyuck Lee¹, Sung-hoon Kim¹, Byeo-ri Kim¹, Ilkwon Kim¹, Hong-Jun Park¹ and Hyuk-soo Kwon¹*
¹ Division of Ecosystem Service & Research Planning, Bureau of Ecological Research, National Institute of Ecology
* Corresponding Author, Email: ulmus@nie.re.kr
Received: Sept 22, 2017; Accepted: July 16, 2018

Key words: Ecosystem Type, Ecosystem Service Mapping, Principal Component Analysis, Spatial Planning

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 Seocheon 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; Martinez-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; Plieninger 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;
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; Tomsha & 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, & Revers, 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. L., 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.

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 | Source                        |
|---------------------------|-----------------------------------|-------------------------------|
| Rice                      | -                                 | Rice paddy                    |
| Barley                    | Hull barley, naked barley, malting barley, wheat, rye |                               |
| Food crops                |                                    |                               |
| Rice paddy                |                                    |                               |
| Barley                    | Hull 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              |                               |
| Leaf vegetables           | Chinese cabbage, cabbage, spinach, lettuce, wormwood, brown mustard, dropwort, leek | Dry field                     |
| Root and bulb vegetables  | Radish, carrot, taro, burdock, lotus root |                               |
| Vegetables                |                                    |                               |
| Chili pepper, Welsh onion, onion, ginger, garlic, Western herbs and vegetables such as rosemary, celery, etc. | Cultivation under structure |
| Condiment vegetables      | Watermelon, oriental melon, cucumber, pumpkin, tomato, strawberry, melon, green chili pepper, eggplant, paprika |                               |
| Fruit vegetables          |                                    |                               |
| Fruits                    | Apple, pear, peach, grape, mandarin, plum, Japanese apricot, citron, kiwifruit, fig, persimmon | Orchard                       |
| Industrial crops          | Sesame, *Perilla*, 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         | Global potential evapotranspiration (PET) - annual, monthly (1950–2000) | CGIAR-CSI^2                     |
| evapotranspiration        |                                                 |                                 |
| Root restricting layer depth | Stock map (1:5000) | Korea Forest Service Canadell et al. (1996) |
| Plant available water     | Forest soil map (1:5000)                        | TaeHoon and YoungKi (2003)      |
| fraction                  |                                                 |                                 |
| 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 database  
^2 CGIAR-CSI: CGIAR-Consortium for Spatial Information  
^3 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 | Stock map (Korea Forest Service) and sub-divided land cover map (Ministry of Environment) | Annual CO₂ absorption (standing timber) and carbon storage (standing timber/litter layer/forest soil) estimates |
| Conversion factors of each species (BWD, BEF, R, CF) |                                                                             |                                                                      |
| Annual CO₂ 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
International, Vol. 7 No. 2 (2019), 21-35

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    | Rice production        | Production area                | Total map area     | ha       |
| services        | Farm production        |                                 |                    |          |
|                 | Polytunnel production  | Water storage                  | Forest             | t/yr     |
|                 |                        | Amount of net CO₂ absorption/ year | Forest, tree stands | t        |
| Regulating      | Carbon                 | Soil erosion of land reserves   | Forest             | t/yr     |
| services        |                        | Scenic quality                 | Total map area     | No. of overlays |
| Cultural        | Recreation             | Scenic overlay                 | Total map area     | Mean no. of photos per month |
| services        |                        | Geo-tagged photos from Flickr   |                    |          |

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.

![Maps of provisioning services](a) Paddy Field (ha) (b) Farm (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 Seocheon 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 Seocheon, and in the reed recreational park (Keeler et al., 2015; Wood et al., 2013).

Figure 3. Mapped provisioning ecosystem services (ha)

Figure 4. Mapped regulating ecosystem services (t)
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:

$$KMO = \frac{\sum_i \sum_{i \neq j} r_{ij}^2}{\sum_i \sum_{i \neq j} r_{ij}^2 + \sum_i \sum_{i \neq j} \alpha_{ij}^2}$$

where $r$ is the elements of the correlation matrix, and $\alpha$ 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 7. Correlation matrix, where red and blue indicate positive and negative correlations, respectively, and the hue intensity represents the strength of the correlation (i.e., darker hues represent higher correlations)

| Indicators | Field | Facility | Orchard | Rice paddy | Underground water | Erosion | Carbon | View | Recreation |
|------------|-------|----------|---------|------------|-------------------|---------|--------|------|------------|
| Field      |       |          |         |            |                   |         |        |      |            |
| Facility   |       |          |         |            |                   |         |        |      |            |
| Orchard    |       |          |         |            |                   |         |        |      |            |
| Rice paddy |       |          |         |            |                   |         |        |      |            |
| Underground water |       |          |         |            |                   |         |        |      |            |
| Erosion    |       |          |         |            |                   |         |        |      |            |
| Carbon     |       |          |         |            |                   |         |        |      |            |
| View       |       |          |         |            |                   |         |        |      |            |
| Recreation |       |          |         |            |                   |         |        |      |            |

Level of significance (one-tailed)

| Field      |       |          |         |            |                   |         |        |      |            |
| Facility   |       |          |         |            |                   |         |        |      |            |
| Orchard    |       |          |         |            |                   |         |        |      |            |
| Rice paddy |       |          |         |            |                   |         |        |      |            |
| Underground water |       |          |         |            |                   |         |        |      |            |
| Erosion    |       |          |         |            |                   |         |        |      |            |
| Carbon     |       |          |         |            |                   |         |        |      |            |
| View       |       |          |         |            |                   |         |        |      |            |
| Recreation |       |          |         |            |                   |         |        |      |            |
Table 8. Total variance explained by each component, extracted by principal component analysis

| Component | Initial eigenvalues | Extraction sums of squared loadings | Rotation sums of squared loadings |
|-----------|---------------------|-------------------------------------|----------------------------------|
| Total     | 2.509 | 27.881 | 27.881 | 2.509 | 27.876 | 27.876 |
| 1         | 1.391 | 15.459 | 15.459 | 1.392 | 15.465 | 15.465 |
| 2         | 1.000 | 11.111 | 54.451 | 1.000 | 54.451 | 54.451 |
| 3         | 0.993 | 11.029 | 54.451 | 0.993 | 54.451 | 54.451 |
| 4         | 0.966 | 10.730 | 76.211 | 0.966 | 76.211 | 76.211 |
| 5         | 0.860 | 9.559  | 85.769 | 0.860 | 85.769 | 85.769 |
| 6         | 0.794 | 8.818  | 94.587 | 0.794 | 94.587 | 94.587 |
| 7         | 0.413 | 4.591  | 99.178 | 0.413 | 99.178 | 99.178 |
| 8         | 0.074 | 0.822  | 100.000| 0.074 | 100.000| 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 | Principle Component 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).
The analysis of ecosystem service maps of Seocheon 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 Seocheon 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 Seocheon 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, CO$_2$, and erosion) and trade-off (e.g., rice paddies vs. underground water and carbon; scenic quality vs. farms, CO$_2$, 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 (Frü h-Mü ller 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.

REFERENCES

Banks-Leite, C., & Ewers, R. M. (2009). "Ecosystem Boundaries". *Els (Essential for Life Science)*. Chichester: John Wiley & Sons Ltd. doi: https://doi.org/10.1002/9780470015902.a0021232.

Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). "Understanding Relationships among Multiple Ecosystem Services". *Ecology Letters*, 12(12), 1394-1404.

Bryce, S. A., & Clarke, S. E. (1996). "Landscape-Level Ecological Regions: Linking State-Level Ecoregion Frameworks with Stream Habitat Classifications". *Environmental Management*, 20(3), 297-311.

Burkhard, B., & Maes, J. (2017). "Mapping Ecosystem Services". *Advanced Books*. doi: https://doi.org/10.3897/ab.el2837.

Burkhard, B., Petrosillo, I., & Costanza, R. (2010). "Ecosystem Services–Bridging Ecology, Economy and Social Sciences". *Ecological Complexity*, 7(3), 257-259.

Cai, W., Gibbs, D., Zhang, L., Ferrier, G., & Cai, Y. (2017). "Identifying Hotspots and Management of Critical Ecosystem Services in Rapidly Urbanizing Yangtze River Delta Region, China". *Journal of Environmental Management*, 191, 258-267.

Canadell, J., Jackson, R., Ehleringer, J., Mooney, H., Sala, O., & Schulze, E.-D. (1996). "Maximum Rooting Depth of Vegetation Types at the Global Scale". *Oecologia*, 108(4), 583-595.

Cimon-Morin, J., Darveau, M., & Poulin, M. (2013). "Fostering Synergies between Ecosystem Services and Biodiversity in Conservation Planning: A Review". *Biological Conservation*, 166, 144-154.

Costanza, R., d'Argè, R., de Groot, R., Farber, S., Grasso, M., Hannon, B. . . . van den Belt, M. (1997). "The Value of the World's Ecosystem Services and Natural Capital". *Nature*, 387(6630), 253-260.

Dittrich, A., Seppelt, R., Vá claví k, T., & Cord, A. F. (2017). "Integrating Ecosystem Service Bundles and Socio-Environmental Conditions – a National Scale Analysis from Germany". *Ecosystem Services*, 28(Part C), 273-282.

Egoh, B., Reyers, B., Rouget, M., Richardson, D. M., Le Maitre, D. C., & van Jaarsveld, A. S. (2008). "Mapping Ecosystem Services for Planning and Management". *Agriculture, Ecosystems & Environment*, 127(1-2), 135-140.
Lee, J.-h., Kim, M., Kim, B., Park, H.-J., & Kwon, H.-s. (2017). "Performing Ecosystem Services at Mud Flats in Seocheon, Korea: Using Q Methodology for Cooperative Decision Making". *Sustainability*, 9(5), 769. doi: [https://doi.org/10.3390/su9050769](https://doi.org/10.3390/su9050769).

Lee, J.-h., Kim, S.-h., & Kwon, H.-s. (2017). "Mapping Interests by Stakeholders' Subjectivities toward Ecotourism Resources: The Case of Seocheon-Gun, Korea". *Sustainability*, 9(1), 93. doi: [https://doi.org/10.3390/su9010093](https://doi.org/10.3390/su9010093).

Li, B., & Wang, W. (2018). "Trade-Offs and Synergies in Ecosystem Services for the Yinchuan Basin in China". *Ecological Indicators*, 84, 837-846.

Lin, S., Wu, R., Yang, F., Wang, J., & Wu, W. (2018). "Spatial Trade-Offs and Synergies among Ecosystem Services within a Global Biodiversity Hotspot". *Ecological Indicators*, 84, 371-381.

Luck, G. W., Chan, K. M., & Klien, C. J. (2012). "Identifying Spatial Priorities for Protecting Ecosystem Services". *F1000Research*, 1. doi: [https://dx.doi.org/10.12688/F1000research.1-17.v1](https://dx.doi.org/10.12688/F1000research.1-17.v1).

Maes, J., Egoth, B., Willemen, L., Liqueur, C., Vihervaara, P., Schägner, J. P., ... Zulian, G. (2012). "Mapping Ecosystem Services for Policy Support and Decision Making in the European Union". *Ecosystem Services*, 1(1), 31-39.

Martínez-Harms, M. J., & Balvanera, P. (2012). "Methods for Mapping Ecosystem Service Supply: A Review". *International Journal of Biodiversity Science, Ecosystem Services & Management*, 81(2-1), 17-25.

Martínez-Harms, M. J., Bryan, B. A., Balvanera, P., Law, E. A., Rhodes, J. R., Possingham, H. P., & Wilson, K. A. (2015). "Making Decisions for Managing Ecosystem Services". *Biological Conservation*, 184, 229-238.

Millennium Ecosystem Assessment (MEA). (2005). *Ecosystems and Human Well-Being - Opportunities and Challenges for Business and Industry*. Washington, DC: Island Press.

Mouchet, M. A., Paraccin, E. M., Schulp, C. J. E., Stürck, J., Verkerk, P. J., Verburg, P. H., & Lavorel, S. (2017). "Bundles of Ecosystem (Dis) Services and Multifunctionality across European Landscapes". *Ecological Indicators*, 73, 23-28.

Nahuelhual, L., Carmona, A., Lozada, P., Jaramillo, A., & Aguayo, M. (2013). "Mapping Recreation and Ecotourism as a Cultural Ecosystem Service: An Application at the Local Level in Southern Chile". *Applied geography*, 40, 71-82.

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R. E., Lehner, B., ... Ricketts, T. H. (2008). "Global Mapping of Ecosystem Services and Conservation Priorities". *Proceedings of the National Academy of Sciences*, 105(28), 9495-9500.

Oakley, J. W., Lawing, A. M., Guillen, G. J., & Gelwick, F. (2018). "Defining Ecologically, Geographically, and Politically Coherent Boundaries for the Northern Gulf of Mexico Coastal Region: Facilitating Ecosystem-Based Management". *Ocean & Coastal Management*, 154, 1-7.

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). "Assessing, Mapping, and Quantifying Cultural Ecosystem Services at Community Level". *Land Use Policy*, 33, 118-129.

Prieto-Torres, D. A., & Rojas-Soto, O. R. (2016). "Reconstructing the Mexican Tropical Dry Forests Via an Autocological Niche Approach: Reconsidering the Ecosystem Boundaries". *PLOS ONE*, 11(3), e0150932. doi: [https://doi.org/10.1371/journal.pone.0150932](https://doi.org/10.1371/journal.pone.0150932).

Qin, K., Li, J., & Yang, X. (2015). "Trade-Off and Synergy among Ecosystem Services in the Guanzhong-Tianshui Economic Region of China". *International journal of environmental research and public health*, 12(11), 14094-14113.

Qiu, J., & Turner, M. G. (2013). "Spatial Interactions among Ecosystem Services in an Urbanizing Agricultural Watershed". *Proceedings of the National Academy of Sciences*, 110(29), 12149-12154.

Queiroz, C., Meacham, M., Richter, K., Norström, A. V., Andersson, E., Norberg, J., & Peterson, G. J. A. (2015). "Mapping Bundles of Ecosystem Services Reveals Distinct Types of Multifunctionality within a Swedish Landscape". *AMBIO*, 44(Supplement 1), 89-101.

Raadspepp-Hearne, C., & Peterson, G. (2016). "Scale and Ecosystem Services: How Do Observation, Management, and Analysis Shift with Scale—Lessons from Québec". *Ecology and Society*, 21(3), 16. doi: [http://dx.doi.org/10.5751/ES-08605-210316](http://dx.doi.org/10.5751/ES-08605-210316).

Raadspepp-Hearne, C., Peterson, G. D., & Bennett, E. M. (2010). "Ecosystem Service Bundles for Analyzing Tradeoffs in Diverse Landscapes". *Proceedings of the National Academy of Sciences*, 107(11), 5242-5247.

Redhead, J., Stratford, C., Sharps, K., Jones, L., Ziv, G., Clarke, D., ... Bullock, J. M. (2016). "Empirical Validation of the Invest Water Yield Ecosystem Service Model at a National Scale". *Science of the Total Environment*, 569, 1418-1426.

Saunders, D. A., & Briggs, S. V. (2002). "Nature Grows in Straight Lines—or Does She? What Are the Consequences of the Mismatch between Human-Imposed Linear Boundaries and
Ecosystem Boundaries? An Australian Example”. *Landscape and Urban Planning, 61*(2-4), 71-82.

Schröter, M., & Remne, R. P. (2016). “Spatial Prioritisation for Conserving Ecosystem Services: Comparing Hotspots with Heuristic Optimisation”. *Landscape Ecology, 31*(2), 431-450.

Schulp, C. J. E., Burkhard, B., Maes, J., Van Vliet, J., & Verburg, P. H. (2014). “Uncertainties in Ecosystem Service Maps: A Comparison on the European Scale”. *PLOS ONE, 9*(10), e109643. doi: https://doi.org/10.1371/journal.pone.0109643.

Sherouse, B. C., Clement, J. M., & Semmens, D. J. (2011). “A Gis Application for Assessing, Mapping, and Quantifying the Social Values of Ecosystem Services”. *Applied geography, 31*(2), 748-760.

Strayer, D. L., Power, M. E., Fagan, W. F., Pickett, S. T. A., & Belnap, J. (2003). “A Classification of Ecological Boundaries”. *BioScience, 53*(8), 723-729.

Swallow, B. M., Sang, J. K., Nyabenge, M., Bundotich, D. K., Duraipappah, A. K., & Yatich, T. B. (2009). “Tradeoffs, Synergies and Traps among Ecosystem Services in the Lake Victoria Basin of East Africa”. *Environmental Science & Policy, 12*(4), 504-519.

Swetnam, R. D., Fisher, B., Mbilinyi, B. P., Murenzi, R. R., & Wolfs, E. M. (2011). “Mapping Socio-Economic Scenarios of Land Cover Change: A Gis Method to Enable Ecosystem Service Modelling”. *Journal of environmental management, 92*(3), 563-574.

TaeHoon, Y., & YoungKi, C. (2003). *Eco-Environmental Hydraulics*. Seoul: Chungmungak.

Tallis, H., Kareiva, P., Marvier, M., & Chang, A. (2008). "An Ecosystem Services Framework to Support Both Practical Conservation and Economic Development". *Proceedings of the National Academy of Sciences, 105*(28), 9457-9464.

Tallis, H., & Polasky, S. (2009). “Mapping and Valuing Ecosystem Services as an Approach for Conservation and Natural-Resource Management”. *Annals of the New York Academy of Sciences, 1162*(1), 265-283.

The Economics of Ecosystems and Biodiversity (TEEB). (2010). *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB*. Malta: Progress Press.

Tieskens, K. F., Schep, S. W., van Beukering, P. J. H., van Beek, I. J. M., & Wolfs, E. M. (2014). "Mapping the Economic Value of Ecosystems on St Eustatius". Netherlands: Institute for Environmental Studies (IVM), VU University Amsterdam. Retrieved from https://www.wolfscompany.com/wp-content/uploads/2014/07/R14-13-Value-mapping-of-nature-on-St-Eustatius.pdf.

Tomscha, S., & Gergel, S. (2016). "Ecosystem Service Trade-Offs and Synergies Misunderstood without Landscape History". *Ecology and Society, 21*(1), 43. doi: http://dx.doi.org/10.5751/ES-08345-210143.

Troy, A., & Wilson, M. A. (2006). "Mapping Ecosystem Services: Practical Challenges and Opportunities in Linking Gis and Value Transfer". *Ecological Economics, 60*(2), 435-449.

Turner, K. G., Odgaard, M. V., Bøcher, P. K., Dalgaard, T., & Svenning, J.-C. (2014). "Bundling Ecosystem Services in Denmark: Trade-Offs and Synergies in a Cultural Landscape". *Landscape and Urban Planning, 125*, 89-104.

White, C., Halpern, B. S., & Kappel, C. V. (2012). "Ecosystem Service Tradeoff Analysis Reveals the Value of Marine Spatial Planning for Multiple Ocean Uses". *Proceedings of the National Academy of Sciences, 109*(12), 4696-4701.

Wood, S. A., Guerry, A. D., Silver, J. M., & Lacayo, M. (2013). "Using Social Media to Quantify Nature-Based Tourism and Recreation". *Scientific Reports, 3*, 2976. doi: https://doi.org/10.1038/srep02976.

Yang, G., Ge, Y., Xue, H., Yang, W., Shi, Y., Peng, C., . . . Chang, J. (2015). "Using Ecosystem Service Bundles to Detect Trade-Offs and Synergies across Urban–Rural Complexes". *landscape and Urban Planning, 136*, 110-121.

Yoon, S. J., Hong, S., Kwon, B.-O., Ryu, J., Lee, C.-H., Nam, J., & Khim, J. S. (2017). “Distributions of Persistent Organic Contaminants in Sediments and Their Potential Impact on Macrobenthic Faunal Community of the Geum River Estuary and Saemangeum Coast, Korea”. *Chemosphere, 173*, 216-226.