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Physical metrics for recreation related ecosystem services and the use of mobile big data for valuation of the services from free-access open spaces

Takashi Hayashi, Daisuke Kunii
(Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries, Japan)
Masayuki Sato
(Kobe University)

1. Introduction

Unlike other ecosystem services, recreational related ecosystem services (RES) are unique in terms of the valuation because their value is recognized only when they are directly used or consumed by people, and it is defined only from a user perspective (SEEA-EA, para 6.117). It encompasses experimental and non-material connection between people and ecosystems (SEEA-EA, para 6.116). As a physical metrics, the number of visits to a specific natural location is regarded as a suitable proxy by considering the number and length of time of interactions with specific features and characteristics of ecosystem concerned (SEEA-EA, para7.49). Therefore, the number of visits is crucial indicator for RES.

For economic valuation of RES in the SEEA context, travel cost method (TCM) is often used for monetary valuation. In the method, the value of ecosystem is estimated by multiplying per capita travel cost, which includes both transportation and opportunity cost, by the number of visits. So, it is important to obtain precise visitation data to estimate the value of RES. In most cases, onsite social survey is used to obtain the data (Dai et al., 2019). However, this survey is suitable where entrances and exits are identified. For free access open spaces which have no identified entrances and exits, e.g., beaches, and rural areas, such kind of survey is not applicable to obtain precise visitation data.

One of the solutions for this issue is to utilize big data, specifically mobile location big data (MLBD) as one of the big data. Although there is no concrete definition of big data, it can be defined by 3V: volume, variety, and velocity or 4V: volume, variety, velocity, and veracity or 5V: volume, variety, velocity, veracity, and value (Gandomi and Haider, 2015). In recent years, its utilization is booming in various research fields (Al-Sai et al., 2022; Tang et al, 2022). In the research field of ecosystem conservation, big data has already been utilized (Worthington, et al., 2020; Runting et al., 2020). More specifically, for the valuation of ecosystems and their services, various studies have conducted particularly for the valuation of cultural ecosystem services (Dai et al., 2019; Wang and Hayashi, 2023; Kim et al., 2019). In the SEEA research field as well, some studies applying big data have been conducted (Hodges et al., 2019; Wetland et al., 2020). Utilization of big data may be able to solve the limitation of collection of visitation data in free access ecosystems.

This study introduces how to utilize big data for the valuation of ecosystem services to enhance accuracy of the value and examines pros and cons of the data. This study focuses on MLBD and applies them to the valuation of RES using cases in Japan.

2. Issues in the valuation of RES

As mentioned in the previous section, unlike other ecosystem services, RES are unique in terms of the valuation because their value is recognized only when they are directly used or consumed by people. For the valuation of the services, TCM is the most frequently applied method (Kaya, 2022; Oras et al., 2022; Cetin et al., 2021). In the method, the number of visits is significant for the valuation, and the value is greatly influenced by it. Therefore, it is important to consider how we can estimate the precise number of visits to a specific ecosystem site.

To collect physical data and information required for the valuation, the most commonly used method is field surveys. So far, most of studies applying TCM have conducted onsite surveys (Kaya, 2022; Cetin et al., 2021; Pelletier et al., 2021; Bertram and Larondelle, 2017). By means of automatic counting by sensors and data collection by surveyors, the number of visits to a specific ecosystem site is counted, and the visitors are regarded as users of RES. Although these data collection methods are effective for areas with specific entrances and exits, the problem is that a leakage of counting when applying to where be free-access open spaces with no specified entrances and exits: e.g., beaches, forests, and rural areas. RESs are not necessarily provided within human-controlled demarcated ecosystems, but are widely provided by various types of ecosystems. Therefore, in a free access ecosystem, current measures may be underestimated.

To solve this issue, we focus on the use of MLBD. MLBD is population and its attribution data obtained from GPS of mobile phones, and mainly provided by mobile network operators. The data rapidly developed in recent years, and some studies have already applied MLBD for valuation of ecosystem services particularly for cultural services (Jaung and Carrasco, 2020; Kubo et al, 2020). From the next section, we examine the possibility to use MLBD for the valuation of RES in the context of SEEA-EA.

3. Data sources of MLBD

In general there are three different types of MLBD: mesh, polygon and point, and each of them has pros and cons for data analysis. Mesh data is easy to estimate visitation in relatively large areas, and to connect with other mesh-formed statistical data. However, mesh data may include not only target area but also other non-target areas, particularly if target areas lay on several meshes or if the areas are small (Figure 1). Therefore, when estimating the number of visits in a specific small area, analysis using mesh data is not suitable, and the results are heavily affected by land use in non-target areas.

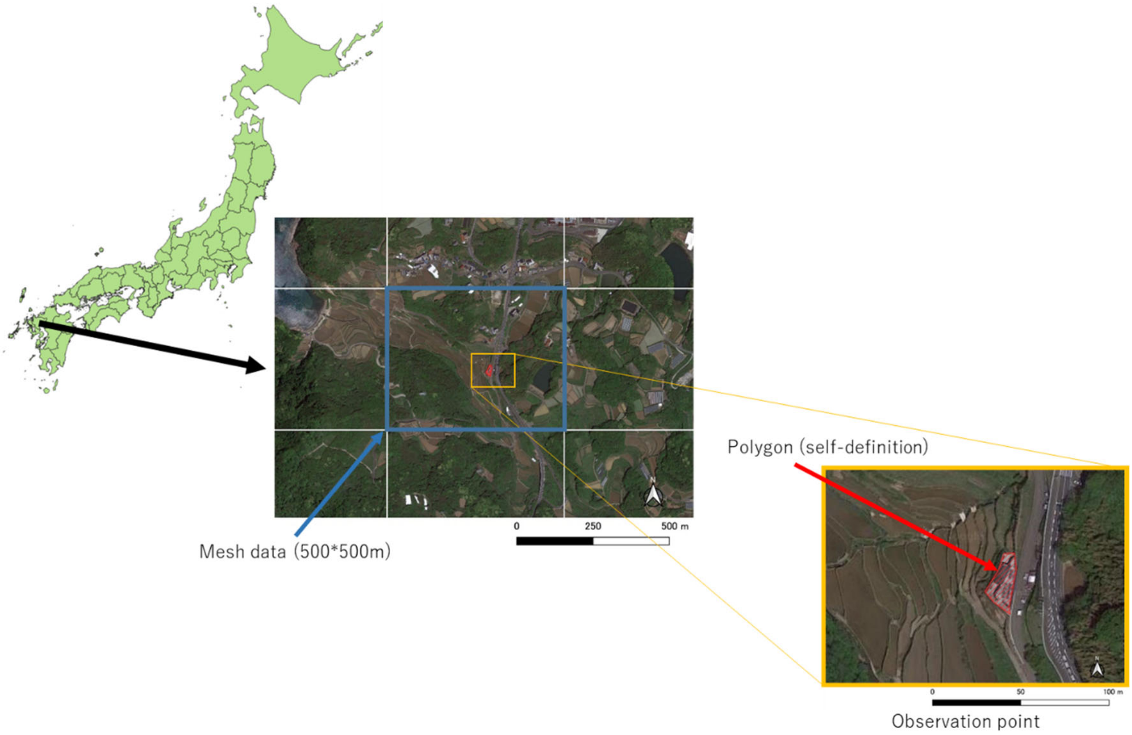

Figure 1 Mesh-formed and polygon data

For polygon data, it is possible to identify a small target area such as, urban green space, one plot of land etc. As it can be defined freely by ourselves and easy to analyze the data where data user wants. However, we have to define a polygon by oneself, and it may in turn be a time-consuming and requires much works especially when target areas are large. The point data is much easier to understand the movement of a person at a street level; from/to where someone come and go. But the data is not also suitable for a larger area. Which data one should apply depends on in which area one should value the ecosystem services; in a nut shell, mesh data is much more suitable to larger area followed by polygon and point data.

Table 1 lists MLBD available in Japan. In Japan, all three types of MLBD are provided by three different providers. The NTT docomo dominates the largest share of the mobile network service: 36%, followed by KDDI: 27% and Softbank: 21% (Ministry of General Affaires and Telecommunications, 2023) respectively. For mesh data, location data is obtained from all users receiving service from the operators, therefore, the number of data-providing customers of NTT docomo is the largest. The data is aggregated by mobile base station and provided as mesh data.

The KDDI provides polygon data and data users can freely define the target areas. In this operator, data is provided only from the customers who have agreed to the provision of location data. So, the number of customers who provide data are much smaller than mesh data provided by NTT docomo and Softbank. Finally, Softbank also provides point data. But data-providing customers are required to install application to one's mobile phone to provide the data, and this makes the number of data-providing customers quite low. Nonetheless, the data is convenient for the analysis of persons' movement in a very small area and facilities such as buildings, urban parks, and streets.

Table 1 Characteristics of different types of mobile location big data

	NTT docomo Softbank	KDDI	Softbank
Data type	･Meshes	･Self-defined polygons	･Self-defined points
Acquisition of data	・By GPS via communication base station	・By GPS function in a gadget	・By a specific application
Attribution of visitors	・Connected with officially certificated data used for mobile phone contracts Age, gender, etc.	・Connected with officially certificated data used for mobile phone contracts Age, gender, etc.	・Data voluntarily registered by users Presumption from registered data
Advantages	・Large number of samples ・Able to combine with other mesh-formed statistical data	・Able to define any areas and to obtain data in the areas ・Able to analyze a specific facility or area	・Able to analyze at street level ・Able to analyze with detailed location data ・Able to analyze on the movement within a small area
Disadvantages	・Data availability depends on the location of communication dase stations, causing low data availability for small population areas	・Data available only for those who accept to the data provision ・Not suitable for analysis of large area	・Data available only for those who use the application AND accept to the data provision ・Possibility for biased data ・Low data availability for small population areas
Sample size	･Huge (Tens of millions)	･Big (Millions)	･Small (Hundreds of thousands)
Suitable to	Larger area ⟷ Smaller area		

4. Application of MLBD for the valuation

4.1 Study sites

We use terraced rice paddies (TRPs) in Kyushu region for the valuation of RES. Kyushu is located in the southern western of Japan and has 6 Prefectures (Figure 1). There are many TRPs in Kyushu among which 47 are selected as "the Best 100 TRPs in Japan." Every year, many visitors come to these TRPs to see beautiful landscapes, and these TRPs provide RES to people (Figure 2). We choose these 48 TRPs to the study sites.

Figure 2 TRPs in Kyushu

4.2 Data collection

For the valuation of RES, the number of visits and their travel distance are essential. All operators provide such kind of data. In this study, considering the size of target area, we apply polygon data for the valuation which is provided by KDDI. Firstly we investigated TRPs whether there are any facilities to accommodate visitors, for example, parking spaces, observation points, resting spaces, and shops by using aerial photos. We defined TRPs with these facilities as those have ability to accept visitors, in other word, ability to supply RES. Among all 48 TRPs in Kyushu, only 16 identified as RES providing TRPs. Next, we identified the area which includes visitor facilities and defined polygons for all 16 identified TRPs to estimate the number of visits. The number of visits and their hometown are obtained rom MLBD. Data is collected for all 16 TRPs in each month from 2018 to 2022, but at moment, we conducted trial data collection for 16 TRPs and only data in May and in September from 2018 to 2021 is gathered.

4.3 TCM

TCM is common methodology to estimate the nonmarket value of ecosystem services particularly for RES. As it is based on the revealed preference and consistent with the SEEA concepts, it is widely applied to valuation ecosystem benefits and service such as forests, national parks, coasts and beaches , protected areas (Zhao, et al, 2022; Jaung and Carrasco, 2020). There are two different types of TCM: zonal TCM and individual TCM; the former estimates the value based on visits per in zone, and the latter based on visits per capita. Both methods evaluate the travel cost based on how many persons come from a designated zone or how many persons come among those who are considered to be beneficiaries. In both cases, the number of visits coming to a specific site is crucial. Therefore, it is important to estimate the figures precisely.

In this study travel cost is estimated by the visitation data including the number of visits and the distance of travel. Considering the travel distance, we estimated their travel cost TC by following equation.

$$TC_i = C_{Ti} * 2 + C_{Oi} \qquad (1)$$

C_{Ti} and C_{Oi} refer to one-way transportation cost and opportunity cost for visitor i respectively. To estimate C_{Ti}, we made some assumptions; as TRPs are often located in mountainous areas with low accessibility by local public transport, we assume visitors use automobile: whether their own or rental, for final access to their sites. We also assume that visitors with direct distance less than 300km comes to a site by automobile (their own car), those who are from 300 to 500km use express trains to the nearest station and then they use rent-a-car from there, visitors from more than 700km uses whether express trains or airplane depending on their availability and convenience, and from the nearest station or the nearest airport, they use rent-a-car. C_{Ti} and travel duration are estimated using NAVITIME, a Japanese online route search engine. Travel duration is used to estimate C_{Oi}. It is the national average wage rate in each year for all visitors multiplied by one third according to previous studies (Jaung and Carrasco, 2020).

4.4 The completion of SEEA-EA for RES in Kyushu

Figure 3 and 4 illustrates SEEA-EA compiled in this study; for Figure 3, each sheet refers to the account for each year. In columns physical accounting and monetary accounting is put in parallel both categorized with from Kyushu inside and from out of Kyushu visitors. In monetary term, “Kyushu inside” refers to local consumption of RES and “Our of Kyushu” refers to export of the services respectively. In rows, monthly data is recorded and aggregated to quarterly and yearly in lower rows, to allow the accounts to be monthly, quarterly and yearly accounts.

The number of visits is recorded in physical accounting as physical metrics and the values estimated by TCM are recorded in monetary accounting. Data for 16 TRPs are aggregated to be recorded to the accounts. At moment, as we only conduct a trial estimation of the visitors, not all cells are filled with figures, and currently we are conducting final estimation.

Figure 4 illustrates a physical supply and use table. It records RES supply from ecosystem assets, which are TRPs in this case, and the use by users: local residents and external (outside Kyushu) residents. Although these accounts are yearly, we can compile the quarterly accounts as well as yearly accounts in other years depending on its needs.

2018 Ecosystem accounting for recreational service of rice paddy terrace in Kyushu

2019 Ecosystem accounting for recreational service of rice paddy terrace in Kyushu

2020 Ecosystem accounting for recreational service of rice paddy terrace in Kyushu

2021	Ecosystem accounting for recreational service of rice paddy terrace in Kyushu					
	Physical accounting			Monetary accounting		
	Number of visitors (presons)			Monetary value (JPY)		
	From Kyushu inside	From out of Kyushu	Total	Domestic consum.	Export	Total
2021/1						
2021/2						
2021/3						
2021/4						
2021/5	5444	206	5650	16,167,483	6,663,398	22,830,882
2021/6						
2021/7						
2021/8						
2021/9	6294	74	6368	13,537,286	3,830,779	17,368,065
2021/10						
2021/11						
2021/12						
1st Qt	0	0	0	0	0	0
2ns Qt	5,444	206	5,650	16,167,483	6,663,398	22,830,882
3rd Qt	6,294	74	6,368	13,537,286	3,830,779	17,368,065
4th Qt	0	0	0	0	0	0
2021 total	11,738	280	12,018	29,704,770	10,494,177	40,198,947

Figure 3 SEEA-EA for TRPs in Kyushu

Note: Figures are tentative.

2018	Units of measure	Economic units				Ecosystem assets				
		Recreation services	Households		Total	Forest	Clopland			Grasslands
			Inside Kyushu	Out of Kyushu			Paddies		Arable land	
							TRPs	Others		
Supply RES	# Visits						8,667			
Use RES	# Visits		7,883	784	8667					

2019	Units of measure	Economic units				Ecosystem assets				
		Recreation services	Households		Total	Forest	Clopland			Grasslands
			Inside Kyushu	Out of Kyushu			Paddies		Arable land	
							TRPs	Others		
Supply RES	# Visits						8,969			
Use RES	# Visits		7,949	1,020	8969					

2020	Units of measure	Economic units				Ecosystem assets				
		Recreation services	Households		Total	Forest	Clopland			Grasslands
			Inside Kyushu	Out of Kyushu			Paddies		Arable land	
							TRPs	Others		
Supply RES	# Visits						9,190			
Use RES	# Visits		8,935	255	9190					

2021	Units of measure	Economic units				Ecosystem assets				
		Recreation services	Households		Total	Forest	Clopland			Grasslands
			Inside Kyushu	Out of Kyushu			Paddies		Arable land	
							TRPs	Others		
Supply RES	# Visits						12,018			
Use RES	# Visits		11,738	280	12018					

Figure 4 SEEA-EA physical supply and use table in Kyushu

Notes: Based on Table 7.6 in SEEA-EA report.

Gray cell indicate not applicable

Figures are tentative.

5. Considerations

Along with our calculation and valuation, we found some pros and cons of utilizing MLBD. Firstly, we found three main advantages of MLBD; one is that visitation data can be easily obtained in open and free access areas, by conventional social survey of automatic counting by sensors, it was not able to obtain the precise number of visits. MLBD opened a new frontier of SEEA valuation, particularly that in rural areas and intact nature. Second, in Japan's case, a couple of data sources is available depending on our valuation targets from local to national scales. This makes valuations more easy and possibility of valuation broaden. We can apply it to valuation at various scale: community, county, region and national (from micro to macro valuation) by utilizing wide variety of data sources. Third, past data is also available for MLBD. We can obtain only present data by social survey, but MLBD enables us valuation in past time. Most of data providers are trying to expand their services to past data. In our case, at first, only data from 2019 was available in 2021 but currently data is extended retroactively from 2018 to present. Compiling SEEA accounts are very hard work and needs much data and information particularly for the valuation. We believe MLBD can help our time-consuming and labor-intensive works such as data collection and on-site survey. We can obtain much benefit from utilization of mobile location big data.

Although MLBD hold the possibility to improve the valuation of ecosystems, there also are some challenges; the biggest one is that in all types of MLBD, the data provided to public is anonymized, and are not actual visitation figures and manipulated by data supplier due to constraint on the provision of private information. For instance, according to KDDI, provided data can be regarded as approximation of the number of actual visits, as they are manipulated considering actual population of specific area, acceptance rate of the data provision among mobile users, and the market share of the company. However, as equations to estimate the approximation are not open to public, we are unable to confirm whether the figures are precise or how large disparity they have. The second one is that the data is updated at any time.

According to our calculation, there is a big disparity between data obtained in January 2023 and that obtained in June 2023. This means that results vary depending on the date we conduct the valuation and causing unreliability of the valuation. In addition, the aggregation of dairy data is not consistent with monthly data; daily data multiplied by 30 is not equal to monthly data, which causes some problems when we compile quarterly or monthly accounts. Third one is missing link with visitors' information. For TCM, basic information of visitors is important but MLBD cannot be linked with the info due also to privacy issue. These challenges may lead to inaccurate valuation and is unable to conduct in-depth analysis. So at moment, the contribution of MLBD to precise estimation of visitors is small.

6. Conclusions

Recently, the development of big data is accelerating worldwide, and we investigated the possibility to utilize the data for valuations of ecosystems and their service particularly for RES. The advantages of MLBD are; (1) Visitation data can be obtained in open and free access areas, (2) In Japan, a couple of data sources is available depending on our valuation targets from local to national scales, (3) Past data is available, which enables us to valuation in past time. Compiling SEEA accounts are very hard work and needs much data and information particularly for the valuation. We believe MLBD can help our time-consuming and labor-intensive works such as data collection and on-site survey. We can obtain much benefit from utilization of mobile location big data.

However, there are some challenges for utilization of MLBD as discussed in Section 5, and these challenges are crucial to the valuation. Therefore, unfortunately we have to conclude that at moment contribution of MLBD to the precise estimation of visitors is very small. Nonetheless, big data including MLBD is still in the stage of development and will be improved and updated, and the data will be much accumulated in the near future. Authors will continue to keep eye on the development and improvement of big data. We believe that it is important to utilize these new data sources in the context of SEEA framework and concepts and to discuss how we can utilize it.

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Short biography (Takashi Hayashi)

Takashi Hayashi is a research director of the Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries (PRIMAFF), Japan. His major fields are agricultural economics and ecological economics. His research fields are agri-environmental policy particularly biomass and bioenergy, and ecosystems and their services.