

High Spatial-Temporal Resolution Data across Large Scales Are Needed to Transform Our Understanding of Ecosystem Services

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Many assessments of ecosystem services (ESs; nature's contribution to people [1]) are based on maps of land cover. For example, Costanza et al. [2] estimated the value of global ESs using economic valuations based on land cover and land use data. This method consists of matching an ecosystem type with the potential ESs that they provide. However, within the different types of land cover or land use considered, various environmental factors occurring at finer temporal or spatial scales (e.g., climatic variation) are not well captured. Thus, ES assessments are largely scale dependent, often missing important variables at both large and small scales. More in-depth studies should be encouraged to elucidate the roles of variables other than land cover [3].

Furthermore, ES is an intrinsically socioecological concept [4] and the land cover approach primarily considers broad environmental variables, taking little account of social variables that can impact significantly on the value and types of ES provided. While a land cover approach can give an estimate of potential ES [5], or the ability of an ecosystem to provide a service [6], it does not take into account demand (either synergistic or conflictual) or how people can access the service, as well as local factors that may influence service provision, which are largely ignored [7]. ES flows are known to vary between different groups and socioeconomic settings, as people differ in their preferences as well as the options available to them. In this regard, differences according to people's socioeconomic status and residential location (e.g., urban or rural areas) should be taken into account when quantifying the demand side [8–14].

One of the most substantial challenges hindering our understanding of the interactions between people and nature is that data on many social systems are not collected in a comparable manner to natural systems data [15,16]. Within natural science, the development of sensor technologies (ranging from site-specific moisture and flow sensors up to remote satellite-based sensors) has brought forth unprecedented levels of data availability, providing standardised hourly/daily/weekly data at high spatial resolution (e.g., metres, kilometres) and across vast spatial extents (often globally). However, many aspects of social science have not experienced this step change and so now lag behind in their ability to capture data at both high spatial-temporal resolution and global scales (Figure 1). For example, while much social data collection is often at regular time intervals (e.g., annual) and (at best) geographically representative, the expense and logistic challenge of these efforts precludes data collection at the frequency necessary to capture the socioeconomic drivers or responses to environmental disturbances at scales relevant to current global

challenges. This fundamentally limits our ability to understand the flow of ESs from ecosystems to end-users (beneficiaries).

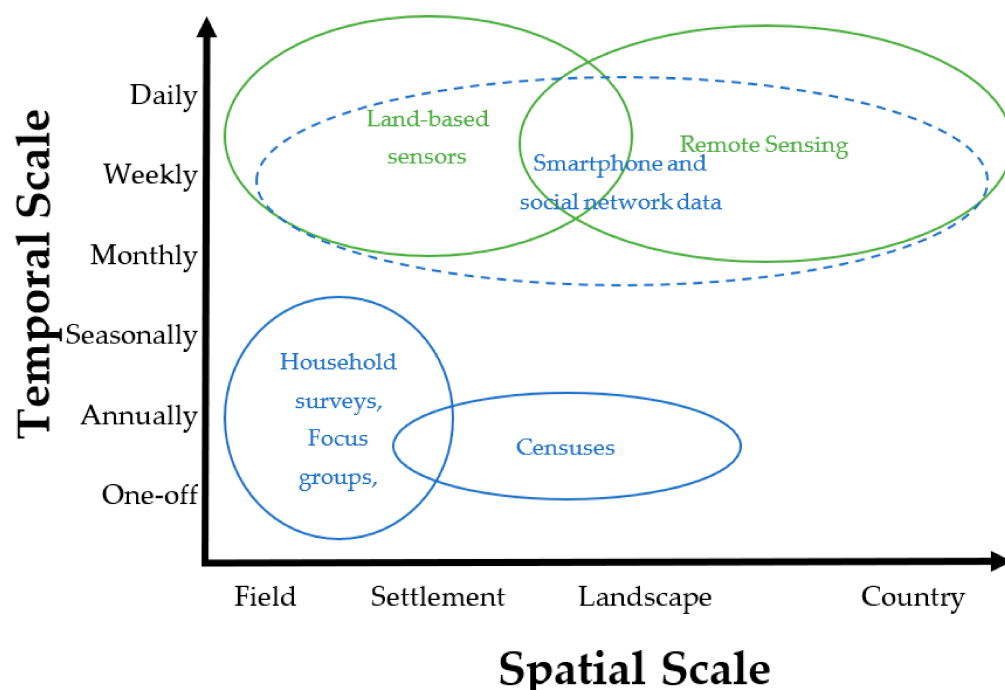


Figure 1. The disconnect between some common social (blue) and ecological (green) data collection methods across space and time. Smartphone and social network data (dashed blue) have the potential to bridge this gap.

Thus, whilst ES research has undoubtedly moved on from the land cover-based benefit transfer methods used to estimate the global value of ecosystem services, and which caused international debate in the late 1990s, large knowledge gaps remain. For example: When can land cover be used as an accurate proxy for ES use? What are the links between the biophysical production of ESs and their use? How can we identify who is using which ESs? Do static inputs (e.g., one-off surveys or satellite images) adequately capture dynamic ES information? Can ES methods be standardised across landscapes, or do different communities require different methods? In order to support evidence-based decision-making, research should strive towards answering these (and many other) questions across a variety of scales [17].

This Special Issue [18] aims to provide a collection of papers that critically evaluate the links between observed land use and ESs. It contains 11 peer-reviewed papers (acceptance rate: ~31%), focusing on eight countries (China, Ethiopia, Germany, India, Kenya, Mexico, Myanmar, and USA). The contributions are written by authors from research organisations spanning 16 countries and six continents; truly a global effort!

Aguilar-Fernández et al. [19] demonstrate that local landscape conditions (e.g., land cover, management, climate) are important determinants of ESs in tropical rangelands. Stein et al. [20] focus on food production in Germany, evidencing that arable crop patterns are partially determined by the local site. Ye et al. [21] support this, arguing that land cover is a major factor in determining ESs. They apply benefit transfer using modified local value coefficients to show how changes in land cover in Guangdong province, southern China, impact ES supply. The study finds that ES value decreased from USD121,666 billion in 1990 to USD116,432 billion in 2018 (−4.3%), predominantly driven by expansion of urban areas. However, they also note that synergy was the dominant relationship among ecosystem services, with 53 pairs of ESs positively correlated (i.e., synergies), and 28 pairs negatively correlated (i.e., trade-offs) between 1990 and 2000. Bai et al. [22] support this finding, using InVEST to show high levels of spatial interactions between ESs, with the majority (10 out of

17) showing synergies rather than trade-offs, grouping them into three bundles to highlight how multiple services can be delivered in combination.

Woldeyohannes et al. [23] employ a similar approach, using land cover data to determine ES value via benefit transfer. However, they contrast and compare two different methods, using global values (obtained from Costanza et al. [24]) and more locally relevant values (from Kindu et al. [25]). In general, the local values are all considerably lower than would be expected if a global valuation was applied, highlighting the importance of considering the users of the land in ES science and how, for a given land cover, different beneficiary groups may result in considerably different land uses, ES values and flows.

Thus, it is vitally important to explicitly consider beneficiaries when studying ESs. Kariuki et al. [26] do just this, asking community elders in southern Kenya about how landscapes have been used over time. They find that, over the last half century, there has been a 30% decline in livestock grazing land due to the expansion of land for agriculture and wildlife conservation. Interestingly, despite this decline, livestock grazing remains the preferred land use in subdivided and privatised lands, potentially highlighting the cultural importance of livelihoods and how this can affect societal values and local prioritisation of ESs.

Prioritisation is further explored by Fetene et al. [27] in relation to urban expansion in Ethiopia. They use community perception to show the ES-related expectations from cropland, agroforestry and grassland, with local people expecting more ESs from agroforestry. However, they evidence a disconnect between local beneficiaries and decision-makers, with the former prioritising food, fodder, water, erosion prevention and compost ESs, whilst the latter substitute compost and water for water regulation and climate regulation. This highlights that different users will exploit the same land covers in very different ways (due to their different priorities) and that scale effects are often prevalent, with global benefits (e.g., climate regulation) prized highly by distant beneficiaries, often at the expense of local people who are unable to access provisioning services to ensure the regulating service is maintained [28,29].

However, different beneficiary groups, whilst socioeconomically disparate, sometimes show surprisingly similarity in ES demand. Welivita et al. [30] provide evidence that beneficiaries in rural, peri-urban and urban areas in and around Hyderabad, India, seem to access ESs in similar ways. They show that beneficiaries across the rural-urban spectrum obtain comparable quantities of ESs with similar levels of direct/indirect access to equally distant ecosystems. This is in contrast to what might be expected from Cumming et al. [31] which would predict rural people have relatively direct relationships with local ecosystems, whereas urban inhabitants often have more indirect access to distant ecosystems.

Zin et al. [32] show similar appreciation of the recreational value of Popa Mountain National Park, Myanmar, across both domestic and international visitors, using two independent methods to evidence the high value of the park (~USD15–20 million per year). Sutton et al. [33] show that national parks in the USA are also extremely valuable, providing USD98 billion per year in ES value. However, they argue that, given this annual benefit, the United States National Park Service is chronically underfunded, and investment in national parks should be increased 10-fold.

Finally, Dolan et al. [34] break ES flow down into two concepts: nature to people (whereby nature moves towards the end-user), and people to nature (whereby the end-user moves towards the natural good). Applying this concept to Welivita et al. [30] shows that urban people often travel shorter distances than rural people to access most ESs, likely because improved infrastructure in urban areas allows for the transport of ESs from wider ecosystems to the locality of the beneficiaries' place of residence.

Dolan et al. [34] highlight that existing movement theories from other disciplines might help ES scientists better understand how people travel to access nature on landscape scales. They also issue a call-to-arms, as identifying which theory/theories best apply to the ES field requires validation data on similar scales. However, as discussed above,

there is often a dearth of social science data at high spatial-resolution across large scales (Figure 1).

In order to address the ongoing problem of how to scale-up social science methods and so advance ES research, two key criteria need to be met: ES scientists need the capability to (1) collect the social data at regular time intervals and over large scales, and (2) analyse these ‘big data’ quickly and efficiently. We suggest that these thresholds have now been achieved. Access to mobile and smartphones is increasing; e.g., in 2005 in the developing world, there were 23 mobile subscriptions per 100 inhabitants and no concept of mobile internet; in 2015, there were 92 mobile subscriptions and 39 mobile internet subscriptions per 100 inhabitants [35]. Alongside falling costs of associated call time and data, this proliferation makes it feasible and affordable to conduct social surveys (and other embedded forms of data) at high-frequencies (via smartphone apps) across national, continental and global scales, even in current data deficient areas such as the Global South [15,16]. Similarly, data from social networks are now readily available and can provide further insight at comparable scales (Figure 1) [36–39]. Computer processing power, and machine learning and artificial intelligence techniques have all improved, allowing these big data to be manipulated and analysed [39–41] on relatively standard desktop computers (e.g., using cloud computing [42]). Thus, there is already high potential to conduct quantitative social science methods at high spatial-temporal resolutions and across large scales, but urgent research is needed into how qualitative data (a foundational element of social science) can be collected across similar scales and which analytic methods can effectively handle such data (and its theoretically informed interpretations) at large scales. As such, we hope this manuscript and associated Special Issue act as a call-to-arms for ES scientists to rapidly investigate and adopt such methods which, we believe, could transform our understanding of ES.

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