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Land

Accepted/In press: 16/07/2021

Peer reviewed version

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Editorial

High spatial-temporal resolution data across large scales are needed to transform our understanding of ecosystem services

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Keywords: Beneficiary; ecosystem service; land cover; land use; social-ecological system; spatiotemporal.

Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Land* **2021**, *10*, x. https://doi.org/10.3390/xxxxx

Academic Editor: Firstname Lastname

Received: date
Accepted: date
Published: date

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).

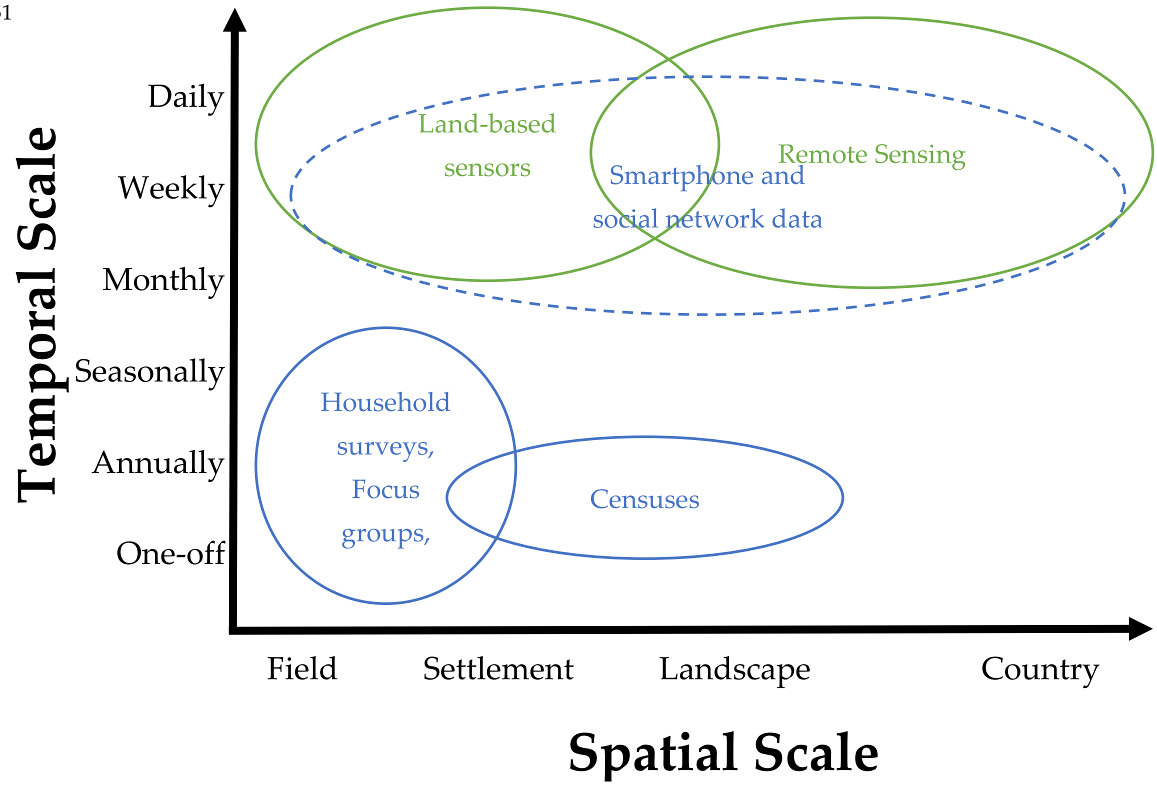

Figure 1. The disconnect between some common social (blue) and ecological (green) data collection methods across space and time. Smartphone and social network data (dashed blue) have the potential to bridge this gap.

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 8 countries (China, Ethiopia, Germany, India, Kenya, Mexico, Myanmar, and USA). The contributions are written by authors from research organisations spanning 16 countries and 6 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, impacts ES supply. The study finds that ES value decreased from US$121,666 billion in 1990 to US$116,432 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 (~15-20 million USD per year). Sutton et al. [33] show that national parks in USA are also extremely valuable – providing $98 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 ten-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.

Author Contributions: Writing—original draft preparation: SW; writing—review and editing: all authors; visualization, SW. All authors have read and agreed to the published version of the manuscript.

Funding: SW was funded by UK Research and Innovation grant numbers ES/V004077/1, ES/T007877/1, NE/T00391X/1, ES/R009279/1, and ES/R006865/1. JMB was funded by UKCEH grant 06895 and NERC grant NE/T00391X/1.

Acknowledgments: We are grateful to the MDPI Land team of academic editors and reviewers for assisting with the Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Díaz, S.; Pascual, U.; Stenseke, M.; Martín-López, B.; Watson, R.T.; Molnár, Z.; Hill, R.; Chan, K.M.A.; Baste, I.A.; Brauman, K.A.; et al. Assessing nature's contributions to people. Science 2018, 359, 270–272, doi:10.1126/science.aap8826.
2. Costanza, R.; de Groot, R.; Farberll, S.; Grassot, M.; Hannon, B.; Limburg, K.; Naeem, S.; O, R. V; Paruelo, J.; Raskin, R.G.; et al. The value of the world's ecosystem services and natural capital; 1997;
3. Almagro, M.; Vente, J. de; Boix-Fayos, C.; García-Franco, N.; Aguilar, J.M. de; González, D.; Solé-Benet, A.; Martínez-Mena, M. Sustainable land management practices as providers of several ecosystem services under rainfed Mediterranean agroecosystems. Mitig. Adapt. Strateg. Glob. Chang. 2013 217 2013, 21, 1029–1043, doi:10.1007/S11027-013-9535-2.
4. Burkhard, B.; Pertrosillo, I.; Costanza, R. Ecosystem services – Bridging ecology, economy and social sciences. Ecol. Complex. 2010, 7, 257–259, doi:10.1016/J.ECOCOM.2010.07.001.
5. Haines-Young, R.; Kienast, F. Indicators of ecosystem service potential at European scales: Mapping marginal changes and trade-offs. Ecol. Indic. 2012, 21, 39–53, doi:10.1016/J.ECOLIND.2011.09.004.

6. Bastian, O.; Haase, D.; Grunewald, K. Ecosystem properties, potentials and services – The EPPS conceptual framework and an urban application example. Ecol. Indic. 2012, 21, 7–16, doi:10.1016/J.ECOLIND.2011.03.014.
7. Willcock, S.; Hooftman, D.A.P.; Balbi, S.; Blanchard, R.; Dawson, T.P.; O'Farrell, P.J.; Hickler, T.; Hudson, M.D.; Lindeskog, M.; Martinez-Lopez, J.; et al. A Continental-Scale Validation of Ecosystem Service Models. Ecosystems 2019, 1–16, doi:10.1007/s10021-019-00380-y.
8. Rodrigue, J.-P. (ed) The Geography of Transport Systems; Fifth Edit.; Routledge.: New York, 2020; ISBN ISBN 978-0-367-36463-2.
9. Mayer, M.; Woltering, M. Assessing and valuing the recreational ecosystem services of Germany's national parks using travel cost models. Ecosyst. Serv. 2018, 31, 371–386, doi:10.1016/J.ECOSER.2017.12.009.
10. Wolch, J.R.; Byrne, J.; Newell, J.P. Urban green space, public health, and environmental justice: The challenge of making cities "just green enough." Landsc. Urban Plan. 2014, 125, 234–244, doi:10.1016/j.landurbplan.2014.01.017.
11. Smith, C.; Morton, L.W. Rural Food Deserts: Low-income Perspectives on Food Access in Minnesota and Iowa. J. Nutr. Educ. Behav. 2009, 41, 176–187, doi:10.1016/j.jneb.2008.06.008.
12. Sang, Å.O.; Knez, I.; Gunnarsson, B.; Hedblom, M. The effects of naturalness, gender, and age on how urban green space is perceived and used. Urban For. Urban Green. 2016, 18, 268–276, doi:10.1016/j.ufug.2016.06.008.
13. Jefferson, R.L.; Bailey, I.; Laffoley, D. d. A.; Richards, J.P.; Attrill, M.J. Public perceptions of the UK marine environment. Mar. Policy 2014, 43, 327–337, doi:10.1016/j.marpol.2013.07.004.
14. Sreetheran, M.; van den Bosch, C.C.K. A socio-ecological exploration of fear of crime in urban green spaces - A systematic review. Urban For. Urban Green. 2014, 13, 1–18.
15. Bell, A.R.; Ward, P.S.; Killilea, M.E.; Tamal, M.E.H.; Convertino, M.; Jones, R. Real-Time Social Data Collection in Rural Bangladesh via a 'Microtasks for Micropayments' Platform on Android Smartphones. PLoS One 2016, 11, e0165924, doi:10.1371/journal.pone.0165924.
16. Bell, A.; Parkhurst, G.; Droppelmann, K.; Benton, T.G. Scaling up pro-environmental agricultural practice using agglomeration payments: Proof of concept from an agent-based model. Ecol. Econ. 2016, 126, 32–41, doi:10.1016/j.ecolecon.2016.03.002.
17. Willcock, S.; Hooftman, D.; Sitas, N.; O'Farrell, P.; Hudson, M.D.; Reyers, B.; Eigenbrod, F.; Bullock, J.M. Do ecosystem service maps and models meet stakeholders' needs? A preliminary survey across sub-Saharan Africa. Ecosyst. Serv. 2016, 18, 110–117, doi:10.1016/j.ecoser.2016.02.038.
18. Land | Special Issue : Exploring the Relationships between Land Use and Ecosystem Services Available online: https://www.mdpi.com/journal/land/special_issues/landuse_ES (accessed on Jul 9, 2021).
19. Aguilar-Fernández, R.; Gavito, M.E.; Peña-Claros, M.; Pulleman, M.; Kuyper, T.W. Exploring linkages between supporting, regulating, and provisioning ecosystem services in rangelands in a tropical agro-forest frontier. Land 2020, 9, 1–17, doi:10.3390/LAND9120511.
20. Stein, S.; Steinmann, H.H.; Isselstein, J. Linking arable crop occurrence with site conditions by the use of highly resolved spatial data. Land 2019, 8, doi:10.3390/LAND8040065.
21. Ye, Y.; Zhang, J.; Wang, T.; Bai, H.; Wang, X.; Zhao, W. Changes in land-use and ecosystem service value in guangdong province, southern China, from 1990 to 2018. Land 2021, 10, doi:10.3390/LAND10040426.
22. Bai, Y.; Ochuodho, T.O.; Yang, J.; Agyeman, D.A. Bundles and hotspots of multiple ecosystem services for optimized land management in kentucky, united states. Land 2021, 10, 1–14, doi:10.3390/LAND10010069.
23. Woldeyohannes, A.; Cotter, M.; Biru, W.D.; Kelboro, G. Assessing changes in ecosystem service values over 1985-2050 in response to land use and land cover dynamics in Abaya-Chamo Basin, Southern Ethiopia. Land 2020, 9, doi:10.3390/LAND9020037.
24. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the global value of ecosystem services. Glob. Environ. Chang. 2014, 26, 152–158, doi:10.1016/j.gloenvcha.2014.04.002.
25. Kindu, M.; Schneider, T.; Teketay, D.; Knoke, T. Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands. Sci. Total Environ. 2016, 547, 137–147, doi:10.1016/J.SCITOTENV.2015.12.127.
26. Kariuki, R.W.; Western, D.; Willcock, S.; Marchant, R. Assessing interactions between agriculture, livestock grazing and wildlife conservation land uses: A historical example from east africa. Land 2021, 10, doi:10.3390/land10010046.
27. Admasu, W.F.; Boerema, A.; Nyssen, J.; Minale, A.S.; Tsegaye, E.A.; Passel, S. Van Uncovering ecosystem services of expropriated land: The case of urban expansion in bahir dar, northwest ethiopia. Land 2020, 9, 1–20, doi:10.3390/LAND9100395.
28. Green, J.M.H.; Fisher, B.; Green, R.E.; Makero, J.; Platts, P.J.; Robert, N.; Schaafsma, M.; Turner, R.K.; Balmford, A. Local costs of conservation exceed those borne by the global majority. Glob. Ecol. Conserv. 2018, 14, e00385, doi:10.1016/J.GECCO.2018.E00385.
29. Fisher, B.; Lewis, S.L.; Burgess, N.D.; Malimbwi, R.E.; Munishi, P.K.; Swetnam, R.D.; Kerry Turner, R.; Willcock, S.; Balmford, A. Implementation and opportunity costs of reducing deforestation and forest degradation in Tanzania. Nat. Clim. Chang. 2011, 1, 161–164, doi:10.1038/nclimate1119.
30. Welivita, I.; Willcock, S.; Lewis, A.; Bundhoo, D.; Brewer, T.; Cooper, S.; Lynch, K.; Mekala, S.; Mishra, P.P.; Venkatesh, K.; et al. Evidence of similarities in ecosystem service flow across the rural-urban spectrum. Land 2021, 10, doi:10.3390/LAND10040430.
31. Cumming, G.S.; Buerkert, A.; Hoffmann, E.M.; Schlecht, E.; von Cramon-Taubadel, S.; Tscharntke, T. Implications of agricultural transitions and urbanization for ecosystem services. Nature 2014, 515, 50–57.

32. Zin, W.S.; Suzuki, A.; Peh, K.S.H.; Gasparatos, A. Economic value of cultural ecosystem services from recreation in popa mountain national park, myanmar: A comparison of two rapid valuation techniques. Land 2019, 8, doi:10.3390/LAND8120194.
33. Sutton, P.C.; Duncan, S.L.; Anderson, S.J. Valuing our national parks: An ecological economics perspective. Land 2019, 8, doi:10.3390/LAND8040054.
34. Dolan, R.; Bullock, J.M.; Jones, J.P.G.; Athanasiadis, I.N.; Martinez-Lopez, J.; Willcock, S. The flows of nature to people, and of people to nature: Applying movement concepts to ecosystem services. Land 2021, 10, doi:10.3390/LAND10060576.
35. ITU Key ICT indicators for developed and developing countries and the world (totals and penetration rates). Available online: https://idp.nz/Global-Rankings/ITU-Key-ICT-Indicators/6mef-ytg6.
36. Fox, N.; August, T.; Mancini, F.; Parks, K.E.; Eigenbrod, F.; Bullock, J.M.; Sutter, L.; Graham, L.J. "photosearcher" package in R: An accessible and reproducible method for harvesting large datasets from Flickr. SoftwareX 2020, 12, doi:10.1016/j.softx.2020.100624.
37. Fox, N.; Graham, L.J.; Eigenbrod, F.; Bullock, J.M.; Parks, K.E. Reddit: A novel data source for cultural ecosystem service studies. Ecosyst. Serv. 2021, 50, 101331, doi:10.1016/J.ECOSER.2021.101331.
38. Lazer, D.; Hargittai, E.; Freelon, D.; Gonzalez-Bailon, S.; Munger, K.; Ognyanova, K.; Radford, J. Meaningful measures of human society in the twenty-first century. Nat. 2021 5957866 2021, 595, 189–196, doi:10.1038/s41586-021-03660-7.
39. Scowen, M.; Athanasiadis, I.N.; Bullock, J.M.; Eigenbrod, F.; Willcock, S. The current and future uses of machine learning in ecosystem service research. Sci. Total Environ.
40. Willcock, S.; Martínez-López, J.; Hooftman, D.A.P.; Bagstad, K.J.; Balbi, S.; Marzo, A.; Prato, C.; Sciandrello, S.; Signorello, G.; Voigt, B.; et al. Machine learning for ecosystem services. Ecosyst. Serv. 2018, doi:10.1016/j.ecoser.2018.04.004.
41. Hofman, J.M.; Watts, D.J.; Athey, S.; Garip, F.; Griffiths, T.L.; Kleinberg, J.; Margetts, H.; Mullainathan, S.; Salganik, M.J.; Vazire, S.; et al. Integrating explanation and prediction in computational social science. Nat. 2021 5957866 2021, 595, 181–188, doi:10.1038/s41586-021-03659-0.
42. Martínez-López, J.; Bagstad, K.J.; Balbi, S.; Magrach, A.; Voigt, B.; Athanasiadis, I.; Pascual, M.; Willcock, S.; Villa, F. Towards globally customizable ecosystem service models. Sci. Total Environ. 2019, 650, 2325–2336, doi:10.1016/J.SCITOTENV.2018.09.371.