[GS-02-029] GIS Participatory Modeling

Abstract

Participatory research is increasingly used to better understand complex social-environmental problems and design solutions through diverse and inclusive stakeholder engagement. A growing number of approaches are helping to foster co-production of knowledge among diverse stakeholders. However, most methods don't allow stakeholders to directly interact with the models that often drive environmental decision-making. Geospatial participatory modeling (GPM) is an approach that engages stakeholders in co-development and interpretation of models through dynamic geovisualization and simulations. GPM can be used to represent dynamic landscape processes and spatially explicit management scenarios, such as land use change or climate adaptation, enhancing opportunities for co-learning. GPM can provide multiple benefits over non-spatial approaches for participatory research processes, by (a) personalizing connections to problems and their solutions, (b) resolving abstract notions of connectivity, and (c) clarifying the scales of drivers, data, and decision-making authority. An adaptive, iterative process of model development, sharing, and revision can drive innovation of methods, improve model realism or applicability, and build capacity for stakeholders to leverage new knowledge gained from the process. This co-production of knowledge enables participants to more fully understand problems, evaluate the acceptability of trade-offs, and build buy-in for management actions in the places where they live and work.

Keywords: co-production of knowledge, human-environment interaction, participatory mapping, stakeholder engagement, volunteered geographic information (VGI)

Author & citation

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Explanation

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1. Introduction

Complex socio-ecological challenges require collaboration from diverse stakeholders and integration of knowledge across disciplines. Participatory research has emerged to bring stakeholders and researchers together to frame research questions, co-develop analytical frameworks, and explore alternate scenarios of action (Reed, 2008; Voinov & Bousquet, 2010). A participatory framework can provide novel insights, legitimize environmental decision-making, and produce actionable results. A growing number of tools and methods that incorporate mapping, geographic information systems (GIS), and models are being used to enhance public participation in management and planning. Given the complexity of socio-ecological challenges, models are often essential for understanding, describing, and forecasting system dynamics. Engaging stakeholders in model conceptualization and development enhances opportunities for co-production of knowledge among stakeholders, researchers, and modelers and builds capacity for stakeholders to use that knowledge to meet their needs (Reed, 2008; Lynum et al., 2007). Participatory models that represent data and simulations in a spatially-explicit way have the added benefit of grounding issues in the places where stakeholders live, work, and recreate, but they are rare in practice (Vukomanovic et al., 2019). Geospatial participatory modeling (GPM) is a type of participatory research that leverages geospatial analytics to engage stakeholders in co-developing and co-interpreting dynamic landscape-scale processes and spatially explicit planning scenarios (Vukomanovic et al., 2019). In making challenges spatially and temporally dynamic, GPM highlights personal connections and relevance, demonstrates spatial interactions and connectedness, and clarifies the spatial scales of drivers and decision-making authority. These added benefits can complement existing GIS methods used in public participation and enhance the traditional participatory research process.

Participatory research has increased in the last two decades, as evidence mounts that failure to include diverse perspectives can result in unsupported and ineffective policy and management solutions (Brown and Kyttä, 2014). A research process that engages stakeholders has a wide range of potential benefits that extend beyond the scientific outcomes alone (Reed, 2008; Voinov and Bousquet, 2010). For stakeholders, participatory approaches enhance their understanding of system properties and the potential impacts of alternate solutions to a problem. Engagement can empower stakeholders, create buy-in, lend legitimacy to the scientific process, and increase agency, advancing equity objectives. By incorporating diverse perspectives and local knowledge, researchers and modelers gain novel insights and a better theoretical understanding of the system, ultimately resulting in more effective and relevant scientific outcomes. However, these approaches are embedded within diverse social contexts characterized by conflicting views and skewed power dynamics (Barnaud and Van Paassen, 2013). Diverse perspectives mean potentially wide-ranging attitudes, behaviors, and preferences related to a specific topic. As participatory research evolves, opportunities exist to develop approaches that foster a common understanding of issues and objectives, while simultaneously accommodating differing perspectives, addressing power asymmetries, and empowering marginalized groups (Etienne et al., 2010).

2. Methods for Soliciting Geospatial Information

One way to foster a common understanding among diverse stakeholders is through shared experiences. Mapping exercises (often referred to as participatory mapping) have long been used to facilitate shared experiences and foster inclusivity in decision-making processes. Because of its multidisciplinary origins and utility in applied research, participatory mapping is embedded in numerous participatory approaches (e.g., Participatory Geographic Information Systems, Public Participation Geographic Information Systems, Volunteered Geographic Information, and others). Early participatory mapping data collection methods used simple technology such as paper maps and stickers or pencils, while applications using digital geographic information systems and web-based mapping to facilitate stakeholder engagement in decision-making have rapidly increased in the last two decades (Brown & Kyttä, 2014). Some projects have found that a combination of data collection methods (e.g. using paper maps, static digital maps, and interactive web-maps) are beneficial and allow broader participation (Smart et al., 2021). Common to all participatory mapping approaches, however, is the underlying assumption that humans attach meaning and value to specific places, which can be represented as spatial attributes on a map. Combining seemingly contrasting knowledge systems—subjective human perceptions and values with precise spatial technology and information—in meaningful ways is foundational to advances in participatory mapping research.

Public participation geographic information systems (PPGIS) and participatory geographic information systems (PGIS) evolved to support inclusivity in public participation for planning and decision-making processes (Sieber, 2006). Both PGIS and PPGIS refer to methods for collecting and using place-specific values of stakeholders in a spatially explicit manner for planning and management-related decision processes. Depending on project objectives or research aim, stakeholders can include experts, non-experts, decision makers, affected individuals, or the public. Most frequently associated with formal planning processes in the global North, PPGIS is typically used by government agencies or non-governmental organizations to engage the public more readily in planning (Brown & Kyttä, 2014). In contrast, participatory GIS (PGIS) is commonly used in bottom-up approaches initiated by grassroots groups, non-governmental organizations, and community-based organizations. Both methods have been used extensively across multiple domains with applications in community and neighborhood planning, environmental management, and cultural resource preservation (see Sieber, 2006; Brown & Kyttä, 2014). Related to PGIS/PPGIS, but focused more on the spatial data itself rather than the participatory process, is volunteered geographic information (VGI). Though citizen-initiated and voluntary, VGI efforts largely result in one-way transfer of information. User-generated spatial information can be extracted from online mapping or social applications, facilitating the compilation and analysis of large spatial datasets in ways that provide answers to important place-based research questions (Elwood, 2008). These methods for soliciting information can be used with stakeholders to improve decision-making processes, but can fall short when the process requires iterating on dynamic landscape-scale processes to better understand problems and potential solutions.

3. Added Benefits of Geospatial Participatory Modeling

Maps and GIS can be used to identify place-based landscape values and can also serve as boundary objects that facilitate discussions about complex spatial issues, such as land-use and land cover change, climate change impacts, or infectious disease spread (Voinov et al., 2018; Petrasova et al., 2020). However, place-based landscape values can change over time (Brown and Weber, 2012) because of multiple, interacting internal and environmental drivers (Sherrouse et al., 2017). These complex spatial issues also have temporal dimensions and change in both time and space can be difficult to convey with static maps and GIS. To better understand dynamic processes, geospatial models are beneficial, but underutilized by stakeholders. These models can be confusing and intimidating, but trust and confidence in models can be built if they are conceptualized, developed, and tested with stakeholders (Gaydos et al., 2019). Stakeholders provide context and have knowledge of local processes, feedbacks, and relevant actors and decision makers that can improve models. Co-developing models with stakeholders helps bridge the practitioner-researcher divide and can result in more salient and relevant research outcomes, building capacity for stakeholders to use the knowledge gained throughout the process. Geospatial participatory modeling (GPM) is a participatory approach that leverages geospatial analytics to improve the co-production of knowledge in management and planning contexts. Evolving geospatial analytics tools and techniques aid in the discovery, interpretation, and communication of meaningful patterns in location-based data and models. Geospatial participatory modeling approaches move beyond static maps by integrating temporal inputs (e.g., time-dependent model interactions or interventions) and dynamic landscape processes (e.g., landscape processes that exhibit non-stationarity like biological invasions or urbanization) in the development of data-driven management or planning scenarios. For example, Gaydos et al. (2019) used GPM to engage forest stakeholders in co-developing forecasts of plant disease spread. Working together, stakeholders improved data accuracy and model parameters, co-created scenarios of adaptive management, and evaluated trade offs across space and time. Results indicated that GPM can enhance the degree to which stakeholders comprehend the scope of complex problems and trade-offs between alternate solutions.

Participatory approaches can benefit from the use of system dynamics models, agent-based models, and integrated models to co-produce knowledge about the temporal dimensions of human-environment interactions. Adding a spatial component to these models can help stakeholders examine the effects of spatial characteristics on problem behavior (e.g., feedbacks in space, spatial interactions) over time (Voinov et al., 2018). Combining the temporal and spatial dimensions of models through geospatial participatory modeling advances participatory research processes in several ways. In making an issue spatial, geospatial participatory modeling can help to make the issue personal. The ability to visualize data and spatial processes at locations where stakeholders live, work, and recreate personalizes the problem and motivates stakeholders to take ownership of their actions that either contribute to the problem or facilitate its resolution. The shared experience among stakeholders also fosters connections among community members navigating the same issues. Through computational steering, geospatial participatory modeling also helps stakeholders understand the feedbacks, time lags, and surprises that result from their decisions and perturbations in the environment (Petrasova et al., 2020).

By making connections spatially explicit, participatory geospatial modeling makes identifying pressing challenges and key solutions less abstract. Flowcharts and concept webs are useful to orient problem-solving discussions, but following up those exercises with spatial models can clarify how processes operate across time and space (Voinov and Bousquet, 2010; Voinov et al., 2018). The ability to modify inputs and view alternate outcomes allows stakeholders to see how actions in one location can influence another location. By incorporating dynamic process-based models in the participatory approach, the interconnectedness of landscape processes is made more transparent. These connections are established through shared resources, like roads or water networks, and constraints, like economic policies and development pressures. Collective water management, for example, is an abstract problem that is difficult to address without understanding the locations of water use, the geographic boundaries of the watershed, and the ways in which water flows through the watershed. Visualizing spatial interactions can catalyze new understandings of connectedness. Becu et al (2008) used spatial simulation models to help two villages in Northern Thailand, one upstream and one downstream, understand how unsustainable irrigation practices in the upstream village can result in water scarcity for the downstream village. Through the simulation model, the linkages between these seemingly unconnected villages were made explicit.

Geospatial modeling also requires clarifying the spatial scales of drivers, data, and decision-making authority. Ecological processes, policy interventions, and external forcings are multi-scalar but this element is often overlooked. When considered in terms of their geospatial dimensions however, these scales are made explicit. Geospatial modeling can also illuminate whether processes are exogenous or endogenous to the system. In geospatial participatory modeling, stakeholders can jointly identify the appropriate resolution and extent of geospatial datasets and models, increasing relevance to the issues under consideration. For the products or results of the simulations to be most effective and locally relevant, special attention must be given to the scales at which decisions are made and ecological processes occur. For example, during a demonstration of a disease spread model, Gaydos et al (2019) found that stakeholders were skeptical of the resolution and accuracy of the underlying host distribution data. Stakeholders voiced their concern that inadequacies there could influence the spatial dynamics of the simulation model. Stakeholders offered potential options for data refinements to make the tool more relevant for management planning.

4. Common Tools Used in Geospatial Participatory Modeling

Geospatial participatory modeling is predicated on the ability to make complex spatial models applicable by adding local context and ensuring accessibility. Model accessibility is critical for removing barriers between stakeholders and scientists. As such, the right tool or approach will depend on the stakeholder group. In many cases, paper maps and images are effective, easy to work with, and trusted by stakeholders. However, increasingly accessible computational resources, big data, and volunteered geographic information mean that innovative spatial tools are available for geospatial participatory modeling. Simulation exercises can also respond in near real time to alterations or perturbations in the modeled landscape or system, directed by stakeholders' manipulation of data inputs and model parameters. For example, Tangible Landscapes, a GPM platform, creates an inviting interface that brings geospatial models onto a physical 3D space, where stakeholders can guide the model through physical actions rather than through code or software (Gaydos et al., 2019; Petrasova et al., 2020). Stakeholders can then intuitively assess how their actions influence the model outcomes. The technology relies on low-cost hardware and free, open-source software to facilitate stakeholder interactions with geospatial modeling across all levels of GIS expertise (Petrasova et al., 2020).

5. GPM Case Study on Johns Island, South Carolina, USA

Johns Island, South Carolina is the fourth-largest island on the east coast of the United States, with a total area of 220km2. Most of the island lies below 5 m in elevation and is rimmed by large expanses of tidal marsh and forested wetlands. Johns Island was settled predominantly by African Americans after the Civil War and has historical significance to the 20th century civil rights movement. Between 1970 and 2016, the population of Johns Island grew from 7,530 to 16,000, while the percentage of African Americans declined from 41% to 21%. The shift in demographics may be due, in part, to the fragile system of African

American land tenure on Johns Island (Vukomanovic et al., 2019). The island's proximity to downtown Charleston, its position as a thoroughfare to resorts, its iconic landscapes, and its waterfront properties have made it an active location for residential and commercial development. Though once a largely rural, agricultural landscape, there are now numerous high-density developments on those parts of the island annexed by the City of Charleston. Additional development pressures come from the affluent resort islands of Kiawah and Seabrook, reachable only by traveling through Johns Island. Local organizations working to address these challenges include the Center for Heirs' Property Preservation (CHPP), the Lowcountry Land Trust (LLT), and the Progressive Club. The Progressive Club, in particular, has long-term community memory and historical commitment to promoting the wellbeing of the African American community on the island (Vukomanovic et al., 2019).

At the invitation of the three above-mentioned groups, a research team from NC State University held a series of workshops to identify valued landscapes and cultural ecosystem services, quantify the potential impacts of sea level rise and urbanization on ecosystem service provision, and identify areas of overlap between biophysical and cultural services (Smart et al. 2021). Together, these findings were incorporated into a conservation toolkit managed by the Lowcountry Land Trust. Throughout these workshops, researchers incorporated paper maps, digital maps, Geographic Information Systems, and a three-dimensional landscape surface to map important natural and working landscapes and to co-develop alternate scenarios of urbanization with stakeholders that would protect these resources.

The GPM study provided a means to better understand the problem of 'coastal squeeze' on Johns Island. Coastal squeeze is a phenomenon that occurs when natural and cultural resources are squeezed between rising seas on the seaward side and rapid urban expansion on the landward side (Smart et al., 2021). Frameworks that leverage geospatial analytics can bring stakeholders and researchers together to more fully conceptualize and quantify dynamic landscape scale processes like 'coastal squeeze' (Vukomanovic et al., 2019; Smart et al., 2021). The interactions and feedbacks become less abstract when they are made spatially-explicit in dynamic landscape-scale simulations (Gaydos et al., 2019). Maps and geospatial models used during workshops illustrated sea level rise predictions and potential development patterns (Vukomanovic et al., 2019). Stakeholders were able to visualize each of these processes and their potential impacts on locally valuable landscapes. The process also elicited questions about the appropriate conservation mechanisms for lands predicted to be inundated in the future. Explicit consideration of place-specific values in dynamic modeling can be used to proactively identify synergies and conflicts under alternate land-use policy, planning, or conservation scenarios (Bagstad et al., 2016).

The GPM study on Johns Island provided a platform to incorporate the values and preferences of a historically marginalized community, frequently left out of conservation and planning processes. Incorporating equity dimensions into geospatial participatory modeling can guide environmental policies in ways that avoid socially unfair outcomes for already marginalized groups (Barnaud and Van Paassen, 2013). In particular, the approach on Johns Island allowed researchers to collect information on the values of a group with deeply rooted cultural ties to the island. Operationalizing place values by mapping them alongside dynamic environmental processes increases the awareness that diverse stakeholders can have multiple, sometimes conflicting, preferences for resources and ecosystem services (Chan et al., 2012).

6. Conclusion

Though PPGIS, PGIS, and GPM can facilitate a more diverse and equitable participatory process, equitable outcomes are not guaranteed (Barnaud and Van Paassen, 2013). Future research should focus on harnessing geospatial technologies in ways that help address power asymmetries in the participatory process and accommodate the diversity of stakeholder interests. One size does not fit all, thus understanding the stakeholder group, their interests and abilities, and the problems they are working to address is crucial. Different tools can be useful at different stages of the modeling process (e.g., initial discussions vs. parameterizing models vs. interpreting results) and may change as stakeholders become more familiar with the process and comfortable with tools. In some cases, geospatial participatory modeling might best be complemented by other non-spatial tools. An iterative participatory modeling approach, to which geospatial participatory modeling lends itself, gives researchers the opportunity to “try again” if approaches do not resonate at first. Iteration, multiple methods and tools, and encouraging diverse viewpoints are likely to result in more innovative and integrative alternatives. An iterative approach can also build trust and lend agency and legitimacy to stakeholder efforts (Voinov et al., 2018). In turn, maps and model outputs can be leveraged by the stakeholders to advocate for their interests in planning efforts and in guiding conservation priorities. These outputs can legitimize stakeholder values in processes that have historically favored expert opinion and can provide the necessary impetus for better-informed and equitable conservation and planning decisions.

Models, visualization tools, and interaction experiences are getting faster, more complex, and more artful and engaging. These tools and methods present tremendous opportunities to make abstract phenomena personal and relevant to stakeholders, to further understanding of the connectivity between landscapes, actions, and consequences, and to clarify the spatial scales of data, drivers, and decision-makers (Vukomanovic et al. 2019). Using these advancements to develop tools that use intuitive modes of interaction (e.g., tangible or mobile interfaces) help bridge the researcher-practitioner divide, empower stakeholders, and facilitate a more equitable participatory process.

References

Bagstad, K. J., Reed, J. M., Semmens, D. J., Sherrouse, B. C., & Troy, A. (2016). Linking biophysical models and public preferences for ecosystem service assessments: a case study for the Southern Rocky Mountains. Regional Environmental Change, 16(7), 2005-2018.

Barnaud, C. and Van Paassen, A. (2013). Equity, power games, and legitimacy: dilemmas of participatory natural resource management. Ecology and Society, 18(2).

Becu, N., Neef, A., Schreinemachers, P. and Sangkapitux, C. (2008). Participatory computer simulation to support collective decision-making: Potential and limits of stakeholder involvement. Land Use Policy, 25(4):498-509.

Brown, G. and Kyttä, M. (2014). Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. Applied Geography, 46:122-136.

Brown, G. and Weber, D. (2012). Measuring change in place values using public participation GIS (PPGIS). Applied Geography, 34:316-324.

Brugnach, M., & Pahl-Wostl, C. (2008). A broadened view on the role for models in natural resource management: implications for model development. In Adaptive and Integrated Water Management (pp. 187-203). Springer, Berlin, Heidelberg.

Chan, K.M.A., Guerry, A.D., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., Bostrom, A., Chuenpagdee, R., Gould, R., Halpern, B.S., Hannahs, N., Levine, J., Norton, B., Ruckelshaus, M., Russell, R., Tam, J., Woodside, U. (2012). Where are cultural and social in ecosystem services? A framework for constructive engagement. BioScience, 62(8), 744-756.

Elwood, S. (2008). Volunteered Geographic Information: Future Research Directions Motivated by Critical, Participatory, and Feminist GIS. GeoJournal, 72(3-4), 173-183.

Etienne, M., Du Toit, D.R. and Pollard, S. (2011). ARDI: A Co-construction Method for Participatory Modeling in Natural Resources Management. Ecology and Society, 16(1).

Gaydos, D.A., Petrasova, A., Cobb, R.C. and Meentemeyer, R.K., (2019). Forecasting and control of emerging infectious forest disease through participatory modelling. Philosophical Transactions of the Royal Society B, 374(1776), p.20180283.

Lynam, T., De Jong, W., Sheil, D., Kusumanto, T. and Evans, K. (2007). A Review of Tools for Incorporating Community Knowledge, Preferences, and Values into Decision Making in Natural Resources Management. Ecology and Society, 12(1).

Pahl-Wostl, C. (2008). Participation in Building Environmental Scenarios. Pages 105-122 in J. Alcamo (editor), Environmental Futures: The Practice of Environmental Scenario Analysis. Elsevier, Amsterdam, The Netherlands.

Petrasova, A., Gaydos, D. A., Petras, V., Jones, C. M., Mitasova, H., & Meentemeyer, R. K. (2020). Geospatial simulation steering for adaptive management. Environmental Modelling & Software, 133, 104801.

Reed, M. S. (2008). Stakeholder participation for environmental management: a literature review. Biological Conservation, 141(10), 2417-2431.

Sherrouse, B.C., Semmens, D.J., Ancona, Z.H. and Brunner, N.M. (2017). Analyzing land-use change scenarios for trade-offs among cultural ecosystem services in the Southern Rocky Mountains. Ecosystem Services, 26, pp.431-444.

Sieber, R. (2006). Public Participation Geographic Information Systems: A Literature Review and Framework. Annals of the Association of American Geographers 96(3), 491-507.

Smart, L. S., Vukomanovic, J., Sills, E. O., & Sanchez, G. (2021). Cultural ecosystem services caught in a 'coastal squeeze' between sea level rise and urban expansion. Global Environmental Change, 66, 102209.

Voinov, A., & Bousquet, F. (2010). Modelling with Stakeholders. Environmental Modelling & Software, 25(11), 1268-1281.

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P.D., Bommel, P., Prell, C., Zellner, M., Paolisso, M., Jordan, R. and Sterling, E. (2018). Tools and methods in participatory modeling: Selecting the right tool for the job. Environmental Modelling & Software, 109, pp.232-255.

Vukomanovic, J., Skrip, M., & Meentemeyer, R. (2019). Making It Spatial Makes It Personal: Engaging Stakeholders with Geospatial Participatory Modeling. Land, 8(2), 38.