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# Making It Spatial Makes It Personal: Engaging Stakeholders with Geospatial Participatory Modeling

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**Abstract:** Participatory research methods are increasingly used to collectively understand complex social-environmental problems and to design solutions through diverse and inclusive stakeholder engagement. But participatory research rarely engages stakeholders to co-develop and co-interpret models that conceptualize and quantify system dynamics for comparing scenarios of alternate action. Even fewer participatory projects have engaged people using geospatial simulations of dynamic landscape processes and spatially explicit planning scenarios. We contend that geospatial participatory modeling (GPM) can confer multiple benefits over non-spatial approaches for participatory research processes, by (a) personalizing connections to problems and their solutions through visualizations of place, (b) resolving abstract notions of landscape connectivity, and (c) clarifying the spatial scales of drivers, data, and decision-making authority. We illustrate through a case study how GPM is bringing stakeholders together to balance population growth and conservation in a coastal region facing dramatic landscape change due to urbanization and sea level rise. We find that an adaptive, iterative process of model development, sharing, and revision drive innovation of methods and ultimately improve the realism of land change models. This co-production of knowledge enables all participants to 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:** participatory modeling; participatory planning; land change model; decision-making; trade-offs

## 1. Introduction

Solutions to complex social-environmental problems require collaboration among diverse stakeholders, and participatory research frameworks have emerged to help people create realistic alternatives for management and build buy-in for decision-making. Participatory research extends beyond extractive use of information, in that stakeholders work together to frame research questions and provide methodological guidance and input on how to use results for action [1,2]. Such endeavors can both improve and legitimize environmental decision-making and produce actionable results [1,3–5]. They are also predicated on genuine engagement, cooperation, and multi-way learning that are hallmarks of translational ecology approaches [6].

Given that social-ecological challenges are deeply complicated and concern a range of stakeholders with diverse expertise, models that describe system dynamics are essential for conceptualizing interacting processes and for envisioning scenarios of alternate action. Models can deepen understanding of current conditions and possible futures, but perhaps even more importantly, the process of constructing a model can enlighten modelers about the scope of problems they face, by compelling them to think through the parameters. Involving stakeholders in model building thus enhances opportunities for co-learning among various actors. As Voinov and Bousquet [7] (p. 1278) suggest, a participatory "modelling process may offer many benefits beyond deriving results including identifying gaps, gaining an improved understanding of the system, and incorporating multiple perspectives into an understanding of a system." Participatory models that represent data and simulations geospatially have the added benefit of grounding issues in the places where stakeholders live and work, and making abstract connections explicit in a real landscape, but they are surprisingly rare in practice.

In a Web of Science search (12 March 2018; Figure 1), we found that publications reporting participatory research have increased over time, but very few of those research efforts involve geospatial approaches, and most of those do not involve geospatial modeling. Maps are often used in participatory research to identify locations of ecosystem services or perceived value (e.g., [8–11]). Maps can also be boundary objects [12,13] that mediate discussions about problematic issues. However, geospatial modeling moves beyond static maps by integrating inputs and landscape processes to develop data-driven scenarios of alternative management outcomes.

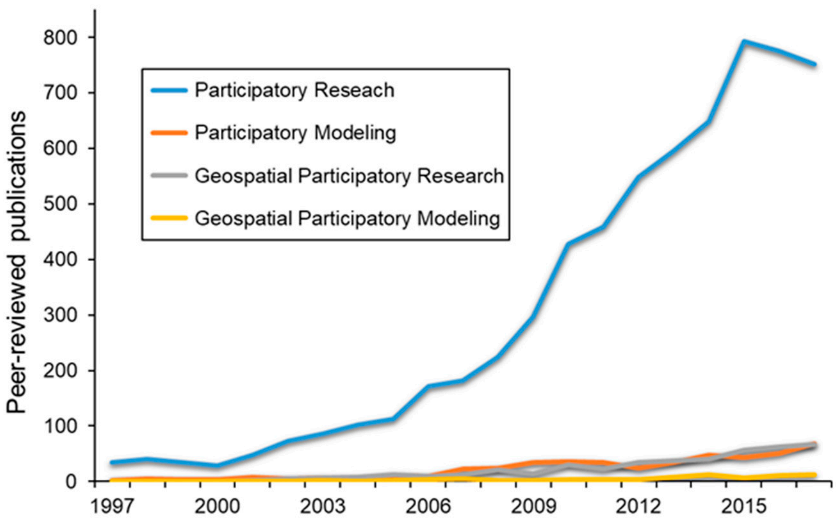


**Figure 1.** Using the search terms "participatory research", "participatory model*", "geospatial participatory research", and "geospatial participatory model*," we found in a Web of Science search that only 8.4% percent of participatory research studies have used geospatial approaches, including static maps, geographic information systems, or other visuals of landscapes (446 of 5321 studies, excluding those in the medical sciences), and only 1.5% of participatory research studies have used geospatial modeling (78 of 5321 studies). "*" search operator includes model, models, modeling, and modelling.

We advance that researchers, planners, and land managers who seek to engage stakeholders in decision-making will benefit from leveraging geospatial analytics, which conceptualizes and quantifies dynamic landscape processes more effectively than non-spatial approaches. Geospatial analytics are the evolving tools and techniques that aid in the discovery, interpretation, and communication of meaningful patterns in location-based data and models. Here, we propose the idea that geospatial participatory modeling (GPM) can confer multiple benefits for participatory research processes, by (a) personalizing connections to problems and their solutions through visualizations of place, (b) resolving abstract notions of landscape connectivity, and (c) clarifying the spatial scales of drivers, data, and decision-making authority. We suggest that geospatial participatory modeling can enhance the degree to which stakeholders comprehend the scope of complex problems and trade-offs of potential solutions. Our objective in this paper is, therefore, to describe these suggested benefits, using illustrative examples from stakeholder workshops conducted during an ongoing GPM project on Johns Island, South Carolina (Table 1). As the project is ongoing, we do not report workshop outcomes (i.e., which ecosystem services stakeholders mapped or prioritized).

**Table 1.** We suggest that geospatial participatory modeling (GPM) can enhance the degree to which stakeholders both individually and collectively comprehend the scope of complex problems and trade-offs of potential solutions through three key benefits.

| Benefits of Geospatial Participatory Modeling (GPM) for Participatory Research | | | |
|---|---|---|---|
| | | **Concept** | **Case Study Example** |
| (1) | Making an issue spatial makes it personal. | Visualization of data and processes at the real locations where stakeholders live and work can (a) show personal contributions or vulnerabilities to local challenges and (b) create shared connections among a community for navigating common concerns. | Modeling the real landscape of Johns Island, SC, showed island residents which homes are predicted to succumb to projected sea level rise and catalyzed discussions about the vulnerability of properties to development pressure and future flooding potential. |
| (2) | Illustrating spatial interaction shows how "what happens here affects there." | Modifying variables in a spatially explicit simulation can show how changes in one area would impact another area, clarifying how both areas are connected by shared resources, such as road or water networks, or constraints, such as economic policies or development pressures. | Considering a land change model, stakeholders on Johns Island realized that conservation easements would likely only shift where development occurs rather than ease total development pressure, leading to discussions of strategies to drive development pressure away from highly valued parcels and closer to existing development. |
| (3) | Geospatial modeling requires defining the often abstract or even overlooked spatial scale of drivers, data, and decision-making. | Mismatches in the scales of local processes that communities care about and regional forces that impact them are often overlooked, but these scales are made explicit when considered in terms of their geospatial dimensions. | The grain and extent of data layers needed to address specific analyses are being co-defined by the stakeholders and research team on Johns Island, forcing the acknowledgment of which scales (such as finer-grain land cover data) are most relevant for decision-making. |

## 2. Johns Island, South Carolina—Background and Methods

Johns Island is an unincorporated settlement on the South Carolina coast, predominantly settled by black Americans after the Civil War [14] (Figure 2). The island has historical significance to the 20th-century civil rights movement and has faced social justice challenges regarding land ownership and development [15]. Heirs' property—-inherited land passed on intestate (without a will) so that all legal heirs own an equal interest in the land but not a specific piece of land—-is common among longstanding black American families on Johns Island. Compounded over several generations, a parcel of land may have hundreds of legal heirs, many of whom no longer reside in the area and who must all agree on land management activities, loans, mortgages, and payment of property tax. Without a clear title, these properties are susceptible to foreclosure due to unpaid property taxes, resulting in loss of the family "home place" [16,17]. Rapid population growth and development is changing the demographics and rural nature of the island;.- over the past 50 years, the total population has more than doubled, but the proportion of black residents has fallen by half. A total population of 7530 (41.2% "Black") in 1970 [18] grew to 16,001 (21.2% "Black or African American alone") by 2016 [19].

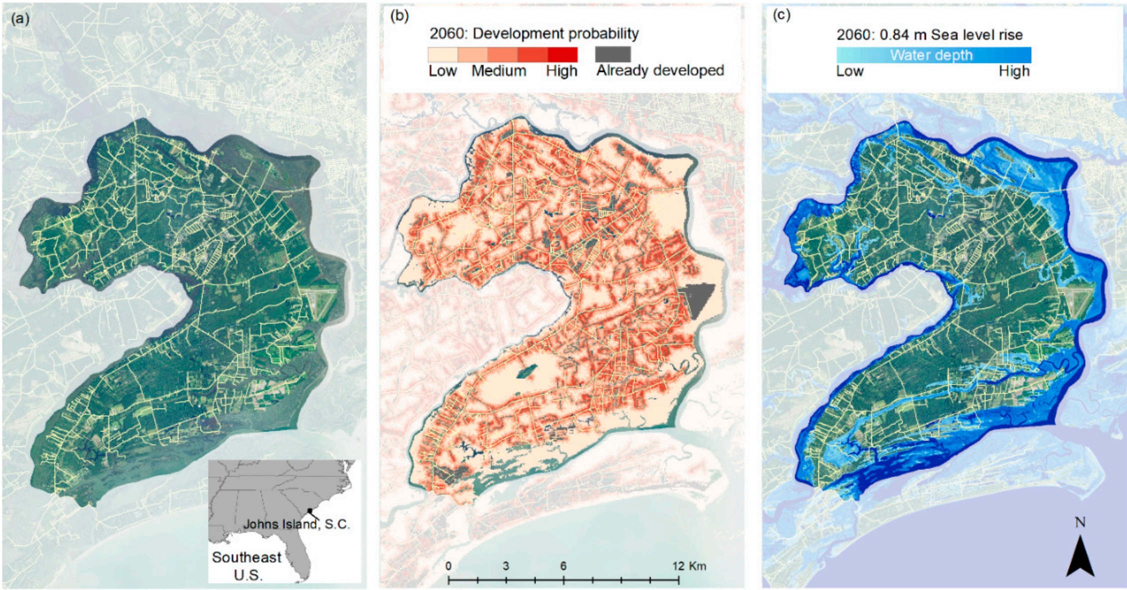


**Figure 2.** (**a**) Johns Island is located in the Lowcountry of coastal South Carolina. (**b**) Rapid population growth and development is projected to lead to a loss of farmland, forest, and wetlands. (**c**) Projected sea level rise is expected to exacerbate development pressure and conflict over land use.

Local organizations working to address social justice challenges on the island include the Center for Heirs' Property Preservation, Lowcountry Land Trust, and Progressive Club. The latter has long-term community memory and a multi-generational history of promoting the wellbeing of the African American community on the island. The Progressive Club has identified development pressure and loss of traditional ways of life as the primary threats to Johns Island's historic landscapes, which include agricultural fields, mixed forest, wetlands, and marine waterways. Development pressure comes both from the growing City of Charleston, which has annexed portions of the island, and from Seabrook and Kiawah Islands to the south, which face over 75% inundation from sea level rise within the next century [20].

At the invitation of the three above groups, our research team arranged a series of workshops (Figure 3) to identify landscapes valuable to island residents for preservation and to formulate development scenarios that would inform a conservation plan (Supplementary Section S1). To avoid problematic power dynamics, the workshops did not include representatives from development firms, whom Johns Island residents reported had historically ignored their perspectives and opinions. Residents were primarily interested in acquiring data, maps, and visuals to strengthen their case for land preservation with county planning officials. At Workshop #1 (17 July 2017), the team met with five members of the Progressive Club to map ecosystem services using points and polygons in a geographic information system (GIS) and with a dozen members of the island's Concerned Citizens Task Force to map ecosystem services on large paper maps with stickers. The research team combined the input in a GIS and then ran spatially explicit scenarios of urban growth on Johns Island using the FUTURES (FUTure Urban-Regional Environment Simulation) land change model [21], comparing projected development under alternative scenarios from 2010–2060 with the locations identified as valuable to workshop attendees (Supplementary Section S2). The scenarios modeled included "business-as-usual" development density, moderate infill (simulating minor regulatory changes or incentives encouraging home building in already developed areas), and aggressive infill (mimicking a regulatory response). At Workshop #2 (29 January 2018), the team presented the results of this initial analysis to a group of twenty island residents, seeking their feedback on the parameterization and results of the model and their input on ranking the most important places to protect. Results of the model runs were displayed on a tangible, three-dimensional representation of Johns Island for participants to examine (Figure 3).


**Figure 3.** At stakeholder workshops, concerned residents of Johns Island, SC, (**a**) identified areas of the island that provide ecosystem services in a geographic information system (GIS); (**b**) ranked conservation priorities of these areas on paper maps; and (**c**,**d**) examined and provided feedback on the results of a geospatial land change model predicting locations of development over the next 50 years.

Residents' feedback is currently being used to refine the FUTURES model through inclusion of finer-grained land use data, parcel-level zoning information, and economic data to estimate land values. The identified areas of high-priority conservation and improved model outputs will contribute to a "conservation toolkit" that will ultimately reflect both landowner preferences and the legal and financial feasibility of conservation mechanisms in high-priority areas, to be used by Johns Island residents and community partners. It will also identify important locations that would likely still face development pressure even with regulatory changes. The Lowcountry Land Trust plans to use short-term financial mechanisms to strategically target places important to residents.

## 3. Benefits of Geospatial Participatory Modeling

### *3.1. GPM Benefit #1: Making An Issue Spatial Makes it Personal*

Many resource challenges that are ubiquitous across large regions (e.g., rapid urbanization or other land use change, water pollution) gain considerable attention as general problems, but the impacts of these issues can seem distant and trivial to a particular community unless conceptualized in their specific landscape. An advantage of using geospatial models during participatory research is the immediate personalization of dynamic processes when they can be visualized in the locations where stakeholders live and work. For example, watershed modeling using high-resolution spatial data and water flow simulations have helped stakeholders discover their own contributions to local and regional water quality and even affected personal behavior change [3,5]. Geospatial participatory simulations have also helped individual farmers understand their roles in the dynamics of their local agro-ecosystem [22].

When geospatial tools are used as a central focus for discussion, representing a communal landscape that is personally valuable, the shared connection and perspective may advance information transfer, social learning, and idea exchange among stakeholders [23,24]. Geospatial models are particularly well-suited to addressing rapidly-changing concerns, such as land conservation of valued areas [24], vulnerability to flooding [25,26], or resource use across landscapes [22,27], that are deeply personal to those with local knowledge of historical challenges and opportunities. Modeling exercises can simulate land use change, sea level change, and urbanization (among other changes) to rapidly illustrate the spatial distribution of potential outcomes of management decisions and to highlight the vulnerabilities of specific properties.

Case Study

On Johns Island, the stakeholders with whom we work are primarily concerned by the loss of open space on the island to development and sea level rise. Their interest in the GPM project stems from an intent to preserve places on the island that are both highly valued and predicted to disappear through inaction. Maps and geospatial models used during workshops illustrated sea level rise predictions during 2010–2100 and potential development through 2060. Sea level has been a topic of general concern for Johns Island residents for some time, but when the sea level rise projections we showed them predicted that individual stakeholders' houses would be underwater, understandably worried participants asked questions like "When is this going to happen?", "Should I sell my home?", and "How good is this model?" Seeing how sea level rise could impact their own backyards increased a feeling of urgency that prompted a discussion about model structures and uncertainty. Researchers who engage stakeholders with geospatial models must be well prepared to handle questions about these topics in non-technical terms, given that modeled future scenarios portraying real places will often be emotionally charged.

Workshop participants also provided valuable feedback for improving the land change model because of their personal knowledge of the island. The local landscapes depicted in geospatial models are not only personally valuable but also personally familiar, and first-hand stakeholder observations can be critical for accurately parameterizing models. Several attendees noted that some areas predicted not to be lost to development by 2060 had been sold to developers and that the model's predictions of land conversion potential for agriculture and forest were the opposite of what they had observed. Overall, the model supported trends that they had themselves witnessed, with one attendee writing after Workshop #2: "Your efforts and willingness to share your data give a lot of folks in that room some much needed optimism because there is scientific validity behind what [they] know to be true. It validates the efforts they've spent fighting in city and county council meetings."

### *3.2. GPM Benefit #2: Spatial Interaction—What Happens Here Affects There*

By making connections spatially explicit, participatory geospatial modeling makes the identification of pressing challenges and key solutions less abstract. Improving water quality in a river, for example, is an abstract problem that is difficult to address without understanding the locations of pollution sources, the geographic boundaries of a watershed, and the ways in which water flows across the land drained by a river. Visualizing spatial interactions, though, can catalyze new understandings of connectedness. Two locations that seem at first to be unconnected may indeed be linked spatially by water flow, road systems, development pressure or a host of other factors. Flowcharts and concept webs are often useful to initially orient problem-solving discussions, but following up those exercises with spatial models that use real data will clarify how processes operate across time and space [7,28].

Understanding the connectivity of landscapes, actions, and consequences is critical to managing areas influenced by social and ecological processes operating nearby or regionally [29]. Often, communities are interconnected for decision-making, because policies enacted in one municipality may affect others linked by shared resources, such as water networks or roads, and land conservation in one area may increase development pressure in another. With geospatial modeling, stakeholders can examine and visualize these types of social-ecological interactions in time and space; complex processes and location data can be explicitly combined to produce an integrated output that demonstrates change in a real landscape. A simulation exercise can also respond in near-real-time to alterations and perturbations in the system, by varying data inputs or model parameters.

Case Study

Population growth in the City of Charleston is impacting local development pressure on Johns Island, and sea level rise on nearby islands will likely increase that pressure over time as populations seek to resettle to higher ground. Realizing that a community and its economy are not spatially isolated can be a revelation for stakeholders. At Workshop #1, a member of the Lowcountry Land Trust experienced a "lightbulb moment" when he realized that a conservation easement on a Johns Island parcel could push development to a different parcel on the island or elsewhere in Charleston County. This notion of connectivity illuminated the spatial impacts of their decisions on future development. Decisions made at strategic locations on Johns Island, whether to sell to developers or to conserve through easements or manage for timber, for example, could impact the likelihood of neighboring parcels being sold and hence collectively determine amounts of preserved open space. Given this possibility, future model development will encompass the entire county, to supplement efforts that have focused exclusively on Johns Island and two neighboring islands, as we intend to help predict where development might go if particular parcels on the island are preserved.

### *3.3. GPM Benefit #3: Clarifying the Spatial Scale of Drivers, Data, and Decision-making*

Connections between communities and ecosystems—whether physical, political, social, or economic—can be fully understood only when the spatial scales of drivers, data, and decision-making are defined. Drivers are the influences that underpin processes, data provide information used to describe a process or pattern, and decision-making authority can vary across time and space. Geospatial approaches improve conceptualizations of environmental problems by addressing all three facets of spatial scale: geospatial models demystify the location(s) and scales of drivers, illuminate what data is required to model processes, and clarify the stakeholders and decision-makers who should be involved in scenario development and evaluation for planning and management. Scale mismatches may exist between what people care about in their communities and where decisions are made [12]. These mismatches in scale are essentially inevitable without the inclusion of geospatial dimensions. As Voinov and Bousquet [7] (p. 1269) assert, "in natural resource management systems the definition of the spatial, social, and ecological boundaries are all part of the problem."

Non-local economic, cultural, and environmental drivers imposed from county, state, regional, and even national levels may restrict options for stakeholders who are attempting to assess and address challenges in their local area [29], and so the scales at which these drivers operate must be identified for any modeling effort. Considering non-local impacts demands a broader understanding of system dynamics, creative solutions, and collaborations that can manage them.

The spatial scale of data, defined as extent (landscape area) and grain (resolution or pixel size), should also be considered carefully during planning exercises that include geospatial participatory modeling. Environmental problems are often articulated as challenges without making clear the spatial extent or the spatial grain at which the problem acts. These scale considerations are shaped by political (regulations, taxes, incentives) and ecological (topography, land cover, hydrology) factors. For example, high-resolution light detection and ranging (LiDAR) data proved invaluable to a GPM project modeling streamflow in Vermont, so that stakeholders could see how pollutants flowed in their own backyards [5]. Such high-resolution data may not be necessary for visualizing conversion of forest patches to development or changes in the ownership of parcels across a large, urbanizing region. However, considering a broad spatial extent may be helpful for discovering and communicating how governance structures and connections between municipalities together influence landscape change at a particular place of interest to stakeholders.

When it comes to decision-making, no optimal solution exists for all stakeholders, and so it is important to understand and articulate the possible trade-offs of different management actions [25], as well as the extent to which stakeholders can control a decision or affect an outcome. Simulations of possible outcomes can help stakeholders judge the acceptability of trade-offs and build consensus regarding where cooperation must occur to realize mutually beneficial results [2].

Case Study

Regarding the drivers affecting development on Johns Island, workshop attendees identified zoning rules set by Charleston County and the City of Charleston as critical and recommended integrating information about allowable housing units per acre into the land change models we have been developing. For example, on the southern portion of the island, some areas with an "agricultural" zoning category have a combined permitted county and city housing density of 1 housing unit/acre, which means that a 20-acre farm could be developed into 20 houses. Zoning decided by governments at the city and county scales has been a consistent source of frustration for Johns Island residents, exemplified by some of their responses during the workshops: "The proverbial Sword of Damocles that hangs over Johns Island right now is where does the city [of Charleston] quit annexing?" "Once they get zoning, they can do what they want to do."

The spatial extent and grain of data that we are using on Johns Island have also been responsive to the feedback and needs of the stakeholders attending workshops. Residents are particularly interested in finer-grain land cover data for the extent of the island and in examining these data overlaid with parcel boundaries. While examining parcel maps, workshop participants noted that land belonging to one individual may consist of multiple adjoining parcels and that a well-known landmark (such as a long-standing family farm) could actually be owned by a number of different people with multiple parcels. Parcel-level information will be important for informing a conservation toolkit, and finer-grained land cover data will better resolve the resources within parcels.

Regarding scales of decision-making, the Johns Island project is largely focused on empowering residents and the land trust to arrange preservation of highly valued areas at a local scale using citizen-driven incentives and agreements, such as easements, payments, and contracts. Sentiments expressed at the workshops echo the lack of influence residents have thus far felt in island governance: "Unfortunately Johns Island is an afterthought for the City of Charleston. It's not their priority." "It's like it's already decided before we get there." "As long as we let those people sitting up in the office making the decisions of who lives here, we're gonna have problems." "We need to put all of our efforts into conserving things, protecting things. Because you know that saying, like, you have to win again and again but a developer only has to win once." "The reason we're here is we all hope we're going to get traction." While land-use policies of local government affect landscape change on the island, decisions by landowners who are not local are also impacting development there, as evidenced by statements made by workshop participants: "What's happening is these farms are being passed down from generation to generation, and then the relatives are living in New York or Chicago or Charlotte, and then they just sell the farm. They sell it to developments." "Heirs' property can be the best thing that ever happened to you, or it could be the worst thing that ever happened to you. We've heard of families in Mount Pleasant—-everybody's had to move because somebody sold." Trade-offs in preservation will be inevitable due to limited financial resources, and so modeling efforts and evaluation of high-priority areas will facilitate consensus.

## 4. What's Next? Co-production of Knowledge Leads to Better Geospatial Models

Solutions to complex sustainability problems will require the sustained involvement of local stakeholders in partnership with researchers, scientists, and decision-makers to fully understand problems, evaluate the acceptability of trade-offs, and build buy-in for management actions that have the potential for lasting positive change. Geospatial models are essential to this process because they intrinsically raise awareness of place and codify the cross-scale interactions inherent in complex systems. For a participatory process to be successful and effective, practitioners must also consider the technical, ethical, and logistical limitations of working with stakeholders and applying their spatial knowledge and data to management decisions [1,2,5,7,28,30–32].

While geospatial models are often developed by researchers with specialized technical expertise, co-learning with stakeholders to improve these models has mutual benefits. In a truly participatory research framework, stakeholders have the right to understand model assumptions and drivers, participate in model development, and feel ownership over the outputs. This co-production of knowledge can lead to more realistic and better-refined alternative futures as well as open up new research frontiers for data scientists.

For example, the FUTURES model outputs that our research team shared with Johns Island stakeholders initially used a version of the model with relatively coarse data inputs. When workshop participants gathered around screens and three-dimensional renderings of the island to examine patterns and processes of landscape change (Figure 3), they spent much time telling the research team how the model could be improved. The team also learned that stakeholders highly valued certain land use types, initiating a reconsideration of what should be prioritized for conservation on the island. This lesson emerged from a discussion of how future residential development was projected to impact the resources that stakeholders identified as important as well as, more generally, reduce the amount of agricultural land and forest patches. These "rural" land cover losses were significant to the stakeholders, even though they had not explicitly identified many of these places as valuable during our initial mapping exercise. We learned that it wasn't necessarily specific places that are important to residents but the island's overall rural nature. Acknowledging the difficulty in mapping "diffuse" resources over discrete landmarks was significant for our understanding of stakeholder values and only possible through an iterative process. Participatory modeling, wherein researchers learn about the unique drivers and local context likely to shape urban growth in a specific region, and wherein stakeholders ask for additional information to improve model results, leads to co-production of knowledge.

Responding to local perspectives and needs of Johns Island residents, we are refining FUTURES to simulate both finer-scale patterns of development and potential repercussions of new roads. A proposed highway expansion, for example, threatens to turn the island into a thoroughfare for new suburbs. Given that roads are a primary driver in the FUTURES model, the inclusion of this proposed highway expansion is a priority for modeling efforts. Stakeholders on Johns Island are also helping us improve the FUTURES model to evaluate the ability of the island to accommodate the relocation of displaced people from sea level rise. Land loss to sea level rise represents a frontier for urbanization and population modeling that will be increasingly important for many rapidly urbanizing coastal areas, representing new research opportunities.

The feedback obtained through an adaptive, iterative process of model development, sharing, and revision will improve the realism of geospatial models and drive the innovation of methods to better include unique characteristics of particular places into model development. At the same time, as stakeholders with local knowledge and expertise have the opportunity to become more familiar with the structure of models and to request additional data and more specific outputs, they will be better equipped with trusted data and map products that address their concerns. And just as importantly, they will feel confident in these outputs when they advocate for their interests. The growing interest in participatory research and modeling is encouraging. We urge researchers, planners, and managers to consider the advantages of geospatial participatory modeling when engaging stakeholders to tackle resource management challenges.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2073-445X/8/2/38/s1, Supplementary—Workshop Methods include Workshop Methods include S.1. Participatory Mapping Workshops (S.1.1 Study Objectives; S.1.2 Workshop Protocol; S.1.3 Workshop Participants; S.1.4 Workshop Facilitators) and S.2. The FUTURES Model.

**Author Contributions:** Conceptualization, J.V., M.M.S., and R.K.M.; Funding acquisition, J.V. and R.K.M.; Investigation, J.V. and M.M.S.; Methodology, J.V.; Project administration, J.V.; Resources, J.V. and R.K.M.; Visualization, J.V.; Writing—original draft, J.V. and M.M.S.; Writing—review and editing, J.V., M.M.S., and R.K.M.

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