Environmental Modelling & Software 92 (2017) 176–188

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Tangible geospatial modeling for collaborative solutions to invasive species management

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ARTICLE INFO

Article history:
Received 13 January 2017
Accepted 20 February 2017
Available online 6 March 2017

Keywords:
Stakeholder engagement
Participatory research
Geospatial modeling
Landscape epidemiology
Forest disease
Tangible user interface

ABSTRACT

Managing landscape-scale environmental problems, such as biological invasions, can be facilitated by integrating realistic geospatial models with user-friendly interfaces that stakeholders can use to make critical management decisions. However, gaps between scientific theory and application have typically limited opportunities for model-based knowledge to reach the stakeholders responsible for problem-solving. To address this challenge, we introduce Tangible Landscape, an open-source participatory modeling tool providing an interactive, shared arena for consensus-building and development of collaborative solutions for landscape-scale problems. Using Tangible Landscape, stakeholders gather around a geographically realistic 3D visualization and explore management scenarios with instant feedback; users direct model simulations with intuitive tangible gestures and compare alternative strategies with an output dashboard. We applied Tangible Landscape to the complex problem of managing the emerging infectious disease, sudden oak death, in California and explored its potential to generate co-learning and collaborative management strategies among actors representing stakeholders with competing management aims.

Software and data availability

Tangible Landscape is available under GNU General Public License and can be downloaded at http://tangible-landscape.github.io together with installation and setup instructions. Tangible Landscape was developed by Anna Petrasova and Vaclav Petras (Petrasova et al., 2014, 2015). The source code of the epidemiological spread model used in this study is available under GNU General Public License and can be downloaded at https://github.com/f-tonini/SOD-modeling with installation and setup instructions as well as set of GIS layers necessary to run the model. The code was developed by Francesco Tonini and based on the original epidemiological framework presented by Meentemeyer et al. (2011).

1. Introduction

Critically addressing complex environmental problems requires cross-disciplinary participatory approaches that facilitate stakeholder engagement and improve the development of collective management strategies (Cabin et al., 2010; Reed, 2008; Stokes et al., 2006; Voinov and Bousquet, 2010; Voinov et al., 2016). However, the substantial research effort devoted to the study of large-scale problems such as biological invasions has overwhelmingly focused on generating model-based understanding of invasion dynamics, rather than implementation of management and intervention, creating what has become known as the knowledge-practice gap (Esler et al., 2010; Matzek et al., 2014). Biological invasions pose a severe threat to ecosystem services and public health worldwide (Daszak, 2000; Hatcher et al., 2012; Kilpatrick et al., 2010), with average annual global economic costs

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http://dx.doi.org/10.1016/j.envsoft.2017.02.020

exceeding those of natural disasters (Lovett et al., 2016; Ricciardi et al., 2011). Yet, scholarly incentives to build knowledge irrespective of practice (Matzek et al., 2015), and mismatches between research and stakeholder priorities (e.g., academic priorities to publish ecological studies and stakeholder priorities to find management solutions, Bayliss et al., 2013) have limited the generation of evidence-informed solutions. In the management of invasive species, the application of knowledge-based tools has been problematic in landscapes that include a mosaic of management jurisdictions (Epanchin-Niell et al., 2009; Stokes et al., 2006), often resulting in competing interests between stakeholders and confusion as to who makes resource allocation decisions, who will benefit, and who pays (Voinov and Bousquet, 2010; Voinov et al., 2016). In consequence, efforts to eradicate or control the spread of invaders have generally been unsuccessful (Simberloff et al., 2005).

One strategy for bridging the knowledge-practice gap involves making scientific models applicable by adding local context and easing accessibility (McCown, 2001). A suggested solution lies in the adoption of participatory modeling frameworks, which iteratively include stakeholders throughout the modeling process, and have been shown to maximize information transfer, generate buy-in, and create advocates for actions best supported by complex models (Perera et al., 2006). A special case, participatory simulation, has been proposed to move participants from passive or didactic learning about complex processes to experiential learning through immersion in what Colella (2000) calls the “computational sandbox,” i.e., simulations with realism adequate to temporarily suspend disbelief and constitute a shared experience. However, for complex, place-based problems like biological invasions, participatory modeling efforts have been hindered by a lack of realistic and intuitive geospatial modeling interfaces needed to generate contextualized understanding of spread dynamics among participants, thereby reducing barriers between specialists, management professionals, and stakeholders with varying levels of technical expertise. The availability of such interfaces could communicate complex system dynamics in clear visualizations, help all participants to understand and interpret multidimensional data, and facilitate decision-making consensus among stakeholders.

To address this need, we present Tangible Landscape (Petrasova et al., 2015), a flexible geospatial visualization and analysis platform that enables people with different backgrounds and levels of technical knowledge to direct dynamic computational simulations using simple tangible gestures. This novel approach seeks to bridge the knowledge-action gap by translating models of biological invasions into tools for strategic application to specific invasion challenges in real-world landscapes with targeted practitioner and stakeholder communities (Esler et al., 2010; Kueffer and Hadorn, 2008). Tangible Landscape allows individuals and groups to generate data-driven, spatially and temporally explicit projections of environmental management outcomes in near real-time in order to explore ramifications and risks associated with management action without threat of consequence.

In a pilot exercise to test the capacity of Tangible Landscape to facilitate learning and generate collaborative management strategies, we simulated the management of an emerging forest disease, sudden oak death (SOD, caused by the pathogen *Phytophthora ramorum*). From the onset of the SOD epidemic in California, delays in identifying the pathogen, understanding the mechanisms of spread, and developing management treatments have resulted in the disease becoming established well beyond initial introductions (Meentemeyer et al., 2011; 2015). Time to action is a critical determinant of eradication efficacy for any disease, and the critical time horizon for eradication has passed (Cunniffe et al., 2016); SOD infects 35% of its anticipated range, an increase of 500% from 2006 (Filipe et al., 2012; Meentemeyer et al., 2011). While modeling suggests that large-scale eradication in California is no longer possible, local to landscape-scale efforts are still very useful for protecting high-value trees in priority areas (Cunniffe et al., 2016). There is widespread recognition that collective effort is needed to reach scales of management likely to succeed (Frankel, 2008).

We developed a customized deployment of Tangible Landscape that (1) adapted a dynamic spatially explicit model to a local study system parameterized using data on the spread of *P. ramorum*; (2) enabled place- and time-dependent interaction with the model using tangible representations of disease management actions on a physical model; (3) provided a shared environment for participants to discuss competing management perspectives and learn from each other; (4) created opportunities to develop and compare individual and collective management strategies; and (5) provided a graphic dashboard to track epidemic outcomes and cost of management treatments, providing feedback regarding how interactions influenced simulated disease spread. We role-played several stakeholder typologies associated with the study system and compared the performance of individual strategies with a strategy emerging from stakeholder consensus.

2. Methodology

2.1. Model development

2.1.1. The tangible geospatial modeling interface

Tangible Landscape (Petrasova et al., 2014, 2015), formerly TanGeoMS (Tateosian et al., 2010), is a tangible user interface (TUI) that allows participants to direct computational modeling through tangible gestures on a scaled physical model of a landscape, onto which raster and vector environmental data from a GIS are projected (Fig. 1).

Users conduct typical GIS functions on the projected data, including editing and parameterizing simulation models, as direct manual interactions with the scaled model are detected by continuous automated 3D scanning (Fig. 1a). Changes in the physical model are detected, recorded and input into GIS for visualization, analysis, and simulation, e.g., whenever a user alters model topography (such as sculpting with sand or plasticine), places markers, or moves building blocks. Tangible interaction frees participants from needing prior technical knowledge before directing sophisticated geospatial models. Maps or animations produced during tangible interaction are projected in near real-time, creating visuals that are readily understood and can inform future interaction. A decision support dashboard reports analytics and the results of queries using spreadsheets, charts, and infographics (Figs. 1f and 2d, Fig. 3). Tangible Landscape runs as a Python plugin for GRASS GIS that can be extended using the GRASS Python Scripting Library and R scripting (R Core Team., 2015). System hardware include a computer, a projector, a 3D scanner, and a physical model (Petrasova et al., 2015). Laptops and portable projectors allow Tangible Landscape deployments outside of the lab.

2.1.2. A socio-ecological dilemma: the SOD epidemic in Sonoma Valley

Circa 1995, conspicuous and unexplained tree mortality (Fig. 4) was observed in several locations within central-coastal California