Environmental Research Letters

PERSPECTIVE • OPEN ACCESS

Integrated spatial analysis for human–wildlife coexistence in the American West

To cite this article: Neil Carter *et al* 2020 *Environ. Res. Lett.* **15** 021001

IOP Publishing Environ. Res. Lett. 15 (2020) 021001 https://doi.org/10.1088/1748-9326/ab60e1

Environmental Research Letters

CrossMark

OPEN ACCESS

PUBLISHED
30 January 2020

PERSPECTIVE

Integrated spatial analysis for human–wildlife coexistence in the American West

Neil Carter[1,12], Matthew A Williamson[2], Sophie Gilbert[3], Stacy A Lischka[4], Laura R Prugh[5], Joshua J Lawler[5], Alexander L Metcalf[6], Aerin L Jacob[7], Bray J Beltrán[8], Antonio J Castro[9,10], Abigail Sage[2] and Morey Burnham[11]

1 School for Environment and Sustainability, University of Michigan, Dana Building, 440 Church Street, Ann Arbor, MI 48109, United States of America
2 Human-Environment Systems, Boise State University. 1910 University Dr, Boise, ID 83725, United States of America
3 Department of Fish & Wildlife Sciences, University of Idaho, 875 Perimeter Drive, Moscow, ID 83844, United States of America
4 Department of Fish, Wildlife and Conservation Biology, Colorado State University, 1474 Campus Delivery, Fort Collins, CO 80523, United States of America
5 School of Environmental and Forest Sciences, University of Washington, Box 352100, Seattle, WA 98195, United States of America
6 Human Dimensions Lab, W A Franke College of Forestry and Conservation, University of Montana, 440 CHCB, 32 Campus Drive, Missoula, MT 59812, United States of America
7 Yellowstone to Yukon Conservation Initiative, 200-1350 Railway Ave., Canmore, AB, T1W 1P6, Canada
8 Heart of the Rockies Initiative, 120 Hickory St. Missoula, MT 59801, United States of America
9 Centro Andaluz para la Evaluación y Seguimiento del Cambio Global (CAESCG), Departamento de Biología Vegetal y Ecología, Universidad de Almería, La Cañada de San Urbano, E-04120, Almería, Spain
10 Idaho State University, Department of Biological Sciences, 921 South 8th Avenue, Pocatello, ID 83209, United States of America
11 Department of Sociology, Social Work, and Criminology, Idaho State University, 921 South 8th Avenue, Pocatello, ID 83209, United States of America
12 Author to whom any correspondence should be addressed.

E-mail: nhcarter@umich.edu

Keywords: coexistence, spatial integration, conservation planning, wildlife

Introduction

The future of conservation and human–wildlife relationships in the American West is at a defining moment. The region consists of a mosaic of land-cover types, with large amounts of public land under varying degrees of protection, use, and ownership. This public land provides the foundation for high levels of connectivity and habitat for healthy populations of wildlife, including those with large resource requirements such as large and wide-ranging mammals (Barnes *et al* 2016). However, space for wildlife is under threat in the West. Energy development projects, urban and ex-urban sprawl, increasing road traffic and density, and amenity-driven human migration are dramatically changing the ecological landscape (Leu *et al* 2008). The social landscape is rapidly changing as well, with new residents bringing different worldviews, economic activities, and expectations regarding wildlife and their habitats (Teel and Manfredo 2010). Because maintaining and establishing landscape connectivity for wildlife in part depends on facilitating their movement across privately-owned lands that connect protected areas, balancing disparate human priorities with wildlife conservation across large landscapes in the American West requires novel approaches to conservation practice.

Inclusion of multi-level drivers of social processes and human behavior in spatial analysis and conservation planning represents a tremendous opportunity to improve outcomes for both wildlife and humans in shared landscapes (Lischka *et al* 2018). A growing body of work has demonstrated novel ways to spatially integrate social and ecological factors that can better inform decision making for human–wildlife coexistence under changing conditions (Bryan *et al* 2011, Behr *et al* 2017, Williamson *et al* 2018). Here, we build on that foundation to underscore the utility of integrating social factors into traditional spatial analysis to promote human–wildlife coexistence in the American West.

Conceptual framing for integrated spatial analysis

Contemporary conservation and land use plans integrate a substantial amount of information on landscapes' biophysical characteristics (e.g. land cover, topography, climatic conditions) and the (potentially pervasive) impacts of human actions (e.g. land use, environmental policy) to identify priority locations for conservation and management actions. This information is often generated

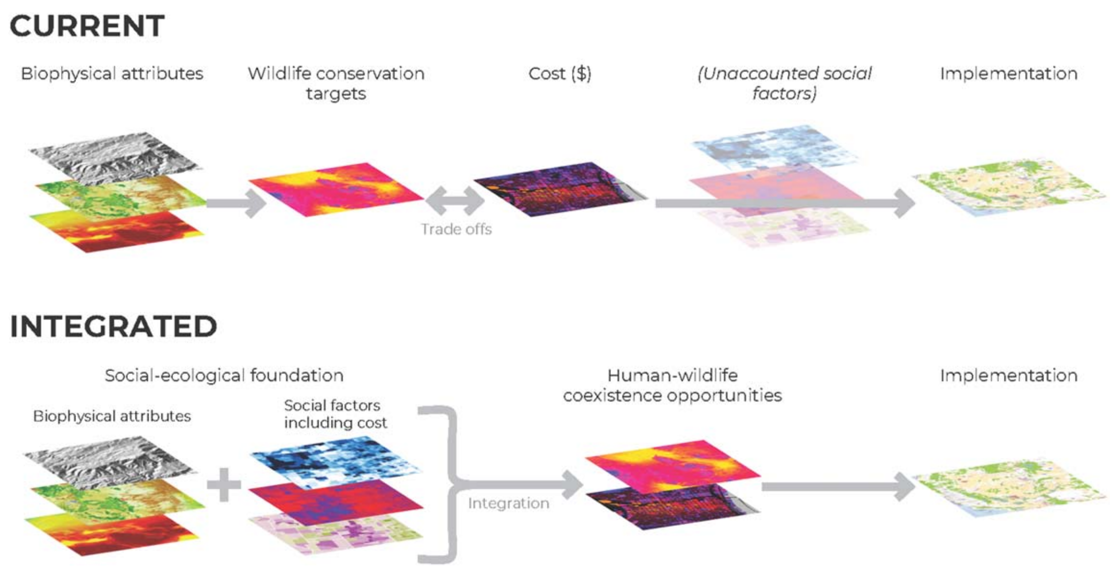

Figure 1. Conceptual framework illustrating two different approaches to developing spatial coexistence strategies. Information on wildlife species attributes are often assessed in contemporary spatial conservation plans (top panel); however, human social factors, like attitudes and institutions, are rarely incorporated. Without these social factors, conservation actions might be less effective than intended, or even counterproductive in shared landscapes. In contrast, an approach based on a social-ecological systems foundation (bottom panel) would integrate social and wildlife spatial data to better identify coexistence opportunities that incorporate various costs and ensure planning success.

using modeled interpolations of habitat suitability and structural or functional connectivity or other conservation metrics. Areas of biophysical importance are considered in conjunction with the monetary costs associated with developing and implementing a conservation plan. However, important social processes such as wealth distribution, institutional and governance structures, worldviews, and human attitudes—all drivers of human behaviors—may intervene to make monetary cost alone a poor proxy for the benefits and costs of coexistence (Carter and Linnell 2016). Failure to adequately consider these seldom used social dimensions will stymie implementation of plans or render them ineffective (figure 1).

We advocate an alternative framework wherein habitat quality, connectivity, or other conservation metrics are derived from attributes of both the biophysical and social landscapes (figure 1). Explicitly incorporating social factors into spatial analysis would allow practitioners to identify locations where coexistence strategies are both biologically critical and socially feasible. Moreover, a broader incorporation of the social factors that inhibit or promote conservation may help identify a more diverse suite of targeted interventions to achieve desired conservation outcomes.

Example Cases of integrated spatial analysis

Several key concepts, metrics, and data types in wildlife and human research are amenable to spatial integration (table 1). Below, we provide three example cases that highlight the value of integrating social dimensions into traditional wildlife-related metrics in the American West.

Integrating social dynamics into habitat assessments

Measuring and mapping animal habitats are core activities of wildlife ecologists. Often spatial trends in human activities, such as urban sprawl, are included as predictors in habitat models via maps of land cover. However, social perceptions and changes in human institutions, attitudes, and behaviors associated with human demographic, cultural, or political change can also have strong effects on wildlife habitats. For example, rapid population growth in many areas of the American West is often associated with a decline in farming and ranching, and an increase in outdoor recreation (Hansen *et al* 2002). Such shifts not only alter habitat characteristics of landscapes (e.g. fragmenting riparian areas) but also the frequency of direct human–wildlife encounters. Furthermore, interactions between economic modernization (e.g. urbanization) and human demography have shifted worldviews toward wildlife (e.g. support for protection) in many parts of the world (Bruskotter *et al* 2017), including in the American West (Teel and Manfredo 2010), affecting how people perceive, value and behave toward wildlife (e.g. emphasizing non-consumptive uses). Thus, changes in the characteristics of humans moving to or from an area may have a strong effect on local wildlife beyond physical changes to habitat (e.g. fragmentation from roads and recreational trails). The effects of changing social dimensions have not yet been sufficiently incorporated into spatial analyses and planning for wildlife conservation.

Table 1. Summary of various concepts and measures in social-ecological science that are amenable to spatial integration for human–wildlife coexistence. We also indicate the degree to which we perceive these different data to be available or discoverable to researchers and practitioners. High = Publically available data covering large spatial extents; Moderate = Available on a project-by-project basis, over small spatial extents; Low = Not available, but possible to develop methods to collect.

Domain	Concept	Definition	Example spatial metrics/data	Spatial data availability
Ecological	Habitat selection/use	Features of geographic space that determine an area's potential to support a species	Habitat suitability index, utility distributions, occupancy	High
	Species distribution	Geographical distribution of occurrence of wildlife species	Animal abundance, species richness, home ranges	High
	Population dynamics	Variation in population size due to birth, death, immigration and emigration rates	Mortality locations, colonized locations, genetic structure	Moderate
	Connectivity	The degree to which a landscape promotes or impedes animal movement between habitat patches	Resistance, least-cost paths, pinch-points	Moderate
Social	Social carrying capacity	Upper and lower limit of tolerance for a wildlife species or population	Tolerance (attitudinal or behavioral) for wildlife, emotional response to wildlife	Moderate to low
	Management/conservation policies and practices	Geographical distribution and magnitude of management or conservation policies and practices	Restoration treatments, land-use, wildlife crossing structures, hunting quotas, grazing intensity	High to moderate
	Human geography	Spatial organization and processes affecting interrelationships between people, places and environments	Demographics, land values, land development rates, amenities, purchasing patterns	High

Incorporating human tolerance in connectivity surfaces

In addition to habitat quality, ecologists often seek to map habitat connectivity, focusing on the factors that impede animal movements across landscapes, such as roads and inhospitable land-cover types. It is possible for wildlife to use human-occupied areas as habitat or movement corridors despite negative attitudes toward those animals, although these attitudes may impede efforts to restore wildlife populations, habitats or connectivity. Moreover, without spatial information on human tolerance, conservation actions may facilitate animal movement to ecological traps, where landscape features appear as suitable habitat yet human intolerance may lead to mortality. For example, human intolerance is a major impediment to reintroduction efforts of predator species, such as grizzly bears (*Ursus arctos horribilis*) or Mexican wolves (*Canis lupus baileyi*), where a large proportion of known mortalities are attributed to management removal or illegal retaliatory killing (USFWS 2016, USGS 2018). Indeed, high-quality biological habitat (e.g. floodplains, berry patches) is often also preferred by humans for development. Mapping human tolerance levels (attitude or behavior) and integrating them into existing analytical approaches for measuring connectivity will help identify priority areas for conservation that better account for the social dimension.

Evaluating spatial patterns of ecosystem services, disservices, and their recipients

Researchers also seek to quantify and map ecosystem services provided by wildlife, such as ecotourism, crop pollination, or waste and pest removal (Lozano *et al* 2019). In other instances, wildlife can be the source of ecosystem disservices or conflicts, such as crop damage or livestock depredation (Ceauşu *et al* 2019). However, a recent global assessment found that current research has emphasized conflicts in lieu of taking into account both benefits and costs of wildlife (Lozano *et al* 2019). Multiple ecosystem (dis)services may spatially overlap, depending on the types of wildlife, people's perceptions and values, and the different human–wildlife interactions that co-occur, producing a landscape where the costs, benefits, and net effects of wildlife on humans depend on multiple intersecting and spatially-related factors (Ceauşu *et al* 2019). As such, the costs and benefits of wildlife populations are often borne by non-overlapping social groups, which can facilitate or limit stakeholder support for the protection of habitat corridors or other conservation actions in shared landscapes. For example, gray wolf (*Canis lupus*) viewing activities in Yellowstone National Park and their associated effects on the regional economy, generated an estimated US$70 million annually to Idaho, Montana, and Wyoming in 2005 (Duffield *et al* 2006). However, from 1989 to 2008, nearly 1000 instances of livestock depredation by wolves occurred in those same three states (Bradley *et al* 2015). In response, 326 partial packs and 48 full packs were killed (Bradley *et al* 2015). The spatial patterns of both wildlife-related ecosystem services and disservices, and their recipients, remain inadequately understood.

Opportunities for spatial data integration and analyses

There are various levels and methods of integrating human and wildlife data (table 2), each of which has its advantages, disadvantages, and outcomes for conservation planning. Below we highlight several promising methods.

Driving the big data revolution are remotely-sensed and social media data, which open up new avenues for spatial integration at unprecedented scales and extents. The increased availability of worldwide high-resolution remote sensing products from a number of sources, such as the National Aeronautics and Space Administration (NASA)'s Landsat, moderate resolution imaging spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS), the European Space Agency (ESA)'s Sentinel, and other ventures, enable inference and prediction of species distributions and their change (Jetz *et al* 2019). When combined with ancillary data, like wildlife population surveys, Earth Observation data enable the spatial characterization of an animal's realized niche, which might be constrained by human worldviews, attitudes, or behaviors. Social media platforms are also an increasingly important source of information for investigating human–nature interactions, including coupling location data with perceptions (e.g. ecosystem services), motivations, and behaviors. For example, recent work extracted data from users of different social media platforms to quantify and map their aesthetic and recreational values toward landscapes across European countries (Van Zanten *et al* 2016).

New analysis techniques, or those from other fields, offer promise for more robust integration of social dimensions into spatial analysis for wildlife conservation planning. Microtargeting, for example, allows conservationists to borrow tools from marketing and political sciences to understand conservation propensity at the individual level (Metcalf *et al* 2019). Coupled with increasing access to spatially explicit data on land ownership, these techniques could allow wildlife conservationists to identify prime corridor areas based on habitat quality and social receptivity. Geospatial tools, common in the field of human geography, can be used to spatially map and predict human tolerances toward wildlife (e.g. Struebig *et al* 2018) and integrate those surfaces into models of landscape resistance to animal movement (i.e. unidirectional relationship in table 2). Likewise, spatializing models of the policy processes (e.g. collaborative

Table 2. Summary of existing ways of integrating social and ecological layers for human–wildlife coexistence. A non-exhaustive list of methods, considerations, and outcomes are described for each level of integration.

Level of integration	Definition	Example analytical methods	Advantages	Disadvantages	Planning outcomes
Implicit	Inferred spatial relationships between humans and wildlife	Co-occurrence mapping and visual inspection of maps	Simple and quick to perform	Unable to quantify or predict relationships, lack of causal understanding	Visual understanding, heuristic for future work
Unidirectional	Spatial effects of humans on wildlife, and vice-versa	Spatial regressions, occupancy analysis, and machine learning	Amenable to disparate data and statistically tractable	Limited causal understanding and predictive capacity	Quantified human–wildlife interactions, spatial predictions of interactions within limit scope, and insights on policy impacts
Bidirectional	Reciprocal human–wildlife spatial interactions	Spatial social-ecological network analysis, agent-based modeling, and scenario analysis	Assess change over time, greater causal understanding, and potentially greater predictive capacity.	Data and computationally intensive, and time consuming	Quantified human–wildlife interactions, spatial & temporal predictions of interactions across different contexts, and evaluation of policy efficacy

governance, Bergsten *et al* 2014) may help identify the policy windows, incentives, and key players and influencers that promoted conservation action in areas where it has already occurred and facilitate the search for similar conditions along animal movement pathways. Co-producing spatial maps with local communities, e.g. through participatory mapping (Ramirez-Gomez *et al* 2016), can provide place-based insights on the spatial overlap of important areas for both humans and wildlife. Integrating social and ecological networks can reveal the interdependencies of human and wildlife communities as well as the consequences of scale mismatch (Bodin *et al* 2019).

Interactions between humans and wildlife are structured in time as well as space. For instance, conservation actions may alter the distribution of species (e.g. increased use of wildlife corridors may bring wildlife into areas where they were previously uncommon), which may alter human attitudes or tolerance towards those species going forward. To assess these changes, dynamic occupancy and spatial capture-recapture models can include various human activities as predictors of the probability that a species (re)occupies or vacates a portion of the landscape through time (Marescot *et al* 2019, table 2). Spatial econometric models can simulate how landowners respond to wildlife-related policies and measure the consequences of these decisions for wildlife conservation (Lewis *et al* 2011). Agent-based models also provide a means of incorporating the complexity of human decision making with the behavioral response of species (Van Schmidt *et al* 2019, table 2). Parameterizing these models could be based on telemetry and accelerometer data that measure an animal's behavioral response to the presence of different human activities (e.g. recreation, hazing), potentially augmented by other forms of wildlife or human data (e.g. remote camera traps, citizen science and social media data).

Conclusion

Although calls have been made in the past to integrate human and wildlife data in spatial analysis and conservation planning, conceptual and methodological hurdles persist. Here, we draw from multiple disciplines and work in various regions to provide suggestions for overcoming those hurdles, and highlight concrete examples of the utility of an integrated approach in shared landscapes, such as those that characterize the American West (Jones *et al* 2019). Mainstreaming integrated spatial analysis into coexistence strategies, however, will require developments in multiple areas, including: overcoming technical challenges of data awareness, processing, and access; establishing new spatial metrics of human social factors, like attitudes; quantifying spatial tradeoffs in human–wildlife interactions, such as in ecosystem (dis)services; protecting highly sensitive, spatial wildlife data (e.g. reproductive locations, high-use areas targeted by poachers) and human data (e.g. confidential information); and quantifying spatial feedbacks between humans and wildlife. Furthermore, as global change becomes ubiquitous and conservation needs and priorities fluctuate in space and time, integrated spatial analysis and conservation planning will need to become an iterative process, requiring increased use of forecasting, decision support frameworks, and involvement with multiple stakeholder groups. Progress in these areas is predicated on people recognizing the value of social-ecological analysis, investing in it, and innovating creative solutions to its constraints. Doing so will help advance the theory and practice of coexistence in globally pervasive shared landscapes.

Acknowledgments

This paper was the result of a workshop in May 2018 in Boise, Idaho, titled 'The social-ecological future of the American West.' The work was supported by the NSF Grant IIA-1301792 to Boise State University, NASA Ecological Forecasting Grant NNX17AG36G to NHC, and a NSF DEB-1652420 to LRP.

Data availability

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID iDs

Neil Carter https://orcid.org/0000-0002-4399-6384
Matthew A Williamson https://orcid.org/0000-0002-2550-5828
Alexander L Metcalf https://orcid.org/0000-0001-9532-585X

References

Barnes M D *et al* 2016 Wildlife population trends in protected areas predicted by national socio-economic metrics and body size *Nat. Commun.* **7** 12747

Behr D M, Ozgul A and Cozzi G 2017 Combining human acceptance and habitat suitability in a unified socio-ecological suitability model: a case study of the wolf in Switzerland *J. Appl. Ecol.* **54** 1919–29

Bergsten A, Galafassi D and Bodin Ö 2014 The problem of spatial fit in social-ecological systems: detecting mismatches between ecological connectivity and land management in an urban region *Ecol. Soc.* **19** 6

Bodin Ö *et al* 2019 Improving network approaches to the study of complex social–ecological interdependencies *Nat. Sustain.* **2** 551–9

Bradley E H, Robinson H S, Bangs E E, Kunkel K, Jimenez M D, Gude J A and Grimm T 2015 Effects of wolf removal on livestock depredation recurrence and Wolf recovery in Montana, Idaho, and Wyoming *J. Wildl. Manage.* **79** 1337–46

Bruskotter J T, Vucetich J A, Karns G, Manfredo M J, Wolf C, Ard K, Carter N H, Lopez-Bao J, Gehrt S and Ripple W J 2017 Modernization, risk and conservation of the world's largest carnivores *Bioscience* **67** 646–55

Bryan B A, Raymond C M, Crossman N D and King D 2011 Comparing spatially explicit ecological and social values for natural areas to identify effective conservation strategies *Conserv. Biol.* **25** 172–81

Carter N H and Linnell J D C 2016 Co-adaptation is key to coexisting with large carnivores *Trends Ecol. Evol.* **31** 575–8

Ceauşu S, Graves R A, Killion A K, Svenning J C and Carter N H 2019 Governing trade-offs in ecosystem services and disservices to achieve human–wildlife coexistence *Conserv. Biol.* **33** 543–53

Duffield J, Neher C J and Patterson D A 2006 Wolves and people in Yellowstone: impacts on the regional economy *Univ. Mont. Final Rep. Yellowstone Park Found.*

Hansen A, Rasker R, Maxwell B, Rotella J, Johnson J, Parmenter A, Langner U, Cohen W, Lawrence R and Kraska M 2002 Ecological causes and consequences of demographic change in the new west *Bioscience* **52** 151–62

Jetz W *et al* 2019 Essential biodiversity variables for mapping and monitoring species populations *Nat. Ecol. Evol.* **3** 539–51

Jones K *et al* 2019 The American West as a social-ecological region: drivers, dynamics and implications for nested social-ecological systems *Environ. Res. Lett.* **14** 115008

Leu M, Hanser S E and Knick S T 2008 The human footprint in the west: a large-scale analysis of anthropogenic impacts *Ecol. Appl.* **18** 1119–39

Lewis D J, Plantinga A J, Nelson E and Polasky S 2011 The efficiency of voluntary incentive policies for preventing biodiversity loss *Resour. Energy Econ.* **33** 192–211

Lischka Stacy A, Teel Tara L, Johnson Heather E, Reed Sarah E, Breck Stewart, Don Carlos Andrew and Crooks Kevin R 2018 A conceptual model for the integration of social and ecological information to understand human-wildlife interactions *Biol. Conserv.* **225** 80–87

Lozano Jorge *et al* 2019 Human-carnivore relations: A systematic review *Biol. Conserv.* **237** 480–92

Marescot L, Lyet A, Singh R, Carter N and Gimenez O 2019 Inferring wildlife poaching in Southeast Asia with multispecies dynamic site-occupancy models *Ecography* **42** 1–12

Metcalf A L, Phelan C N, Pallai C, Norton M, Yuhas B, Finley J C and Muth A 2019 Microtargeting for conservation *Conserv. Biol.* **33** 1141–50

Ramirez-Gomez S O I, Brown G, Verweij P A and Boot R 2016 Participatory mapping to identify indigenous community use zones: implications for conservation planning in southern Suriname *J. Nat. Conserv.* **29** 69–78

Struebig M J *et al* 2018 Addressing human-tiger conflict using socio-ecological information on tolerance and risk *Nat. Commun.* **9** 3455

Teel T L and Manfredo M J 2010 Understanding the diversity of public interests in wildlife conservation *Conserv. Biol.* **24** 128–39

USFWS 2016 *Mexican Wolf Recovery Program: Progress Report #19* US Fish and Wildlife Service, Albuquerque, NM, USA (https://fws.gov/southwest/es/mexicanwolf/pdf/2016MexicanWolfProgressReportFinal.pdf)

USGS 2018 Interagency Grizzly Bear Study Team, 'Known and Probably Grizzly Bear Mortalities in the Greater Yellowstone Ecosystem (https://usgs.gov/data-tools/2018-known-and-probable-grizzly-bear-mortalities-greater-yellowstone-ecosystem)

Van Schmidt N D, Kovach T, Kilpatrick A M, Oviedo J L, Huntsinger L, Hruska T, Miller N L and Beissinger S R 2019 Integrating social and ecological data to model metapopulation dynamics in coupled human and natural systems *Ecology* **100** e02711

Van Zanten B T, Van Berkel D B, Meentemeyer R K, Smith J W, Tieskens K F and Verburg P H 2016 Continental-scale quantification of landscape values using social media data *Proc. Natl Acad. Sci. USA* **113** 12974–9

Williamson M A, Schwartz M W and Lubell M N 2018 Spatially explicit analytical models for social–ecological systems *Bioscience* **68** 885–95