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Synthesis

Iterative scenarios for social-ecological systems

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ABSTRACT. Managing social-ecological systems toward desirable regimes requires learning about the system being managed while preparing for many possible futures. Adaptive management (AM) and scenario planning (SP) are two systems management approaches that separately use learning to reduce uncertainties and employ planning to manage irreducible uncertainties, respectively. However, each of these approaches have limitations that confound management of social-ecological systems. Here, we introduce iterative scenarios (IS), a systems management approach that is a hybrid of the scopes and relationships to uncertainty and controllability of AM and SP that combines the "iterativeness" of AM and futures planning of SP. Iterative scenarios is appropriate for situations with high uncertainty about whether a management action will lead to intended outcomes, the desired benefits are numerous and cross-scale, and it is difficult to account for the social implications around the natural resource management options. The value of iterative scenarios is demonstrated by applying the approach to green infrastructure futures for a neighborhood in the city of Cleveland, Ohio, U.S., that had experienced long-term, systemic disinvestment. The Cleveland green infrastructure project was particularly well suited to the IS approach given that learning about environmental factors was necessary and achievable, but what would be socially desirable and possible was unknown. However, iterative scenarios is appropriate for many social-ecological systems where uncertainty is high as IS accommodates real-world complexity faced by management.

Key Words: *adaptive management; futures; green infrastructure; iterative scenarios; scenario planning; social-ecological systems; structured learning*

INTRODUCTION

Ecosystem management often requires decision making with high uncertainty (Polasky et al. 2011, Memarzadeh et al. 2019, Ulibarri 2019). There are two primary ecosystem management approaches for situations of high uncertainty: adaptive management (AM) and scenario planning (SP; Peterson et al. 2003, Allen et al. 2011). Each has its strengths and limitations in achieving desired natural resource futures, presenting tremendous challenges for ecosystem managers. Exemplifying such challenges is managing for provisioning of ecosystem services.

Understanding ecosystem services, and how to manage for them, is of increasing importance in the face of accelerating environmental change. Ecosystem services are characterized by high degrees of uncertainty in ecological dynamics (Bennett et al. 2009), social valuation (Barnaud and Antona 2014), and decision processes (Polasky et al. 2011). Managing for multiple ecosystem services has proven particularly challenging (Birgé et al. 2016, Dade et al. 2019). Ecosystem services are frequently difficult to manage because different services are often not independent of one another, as the provision of services varies within and across scales, and selecting for one suite of services means a trade-off amongst other competing services (e.g., Feng et al. 2020). As a result, it is difficult to navigate a social-ecological system (SES) toward desirable ecosystem service outcomes or even define what a desirable outcome would be. Some aspects of the management of ecosystem services are controllable, meaning the actors involved can manipulate necessary parts of the ecological system known to influence the system components of interest and have the social capacity to do so, whereas others are less controllable or the controllability itself is uncertain, particularly in situations of managing across scales or managing where social resistance, e.g., land-use policy or cultural expectations, is a factor (Birgé et al. 2016). For ecosystem management, when uncertainty with the SES and controllability of management interventions are high, AM is an appropriate management alternative (Gregory et al. 2006, Allen and Garmestani 2015). However, in cases where uncertainty is high but controllability is low, SP has been employed as the most appropriate ecosystem management alternative (Peterson et al. 2003). However, SP has its own limitations as it does not have a learning component built into its framework; there is no structured, iterative process in SP that allows for monitoring to improve ecosystem management through time (Butler et al. 2020).

Here, we address this issue by proposing an approach—iterative scenarios (IS)— that integrates the strengths of AM and SP while addressing their limitations. Iterative scenarios is suitable in situations in which active learning around reducible uncertainties is possible and needed to inform futures, but the learning must inform management given irreducible uncertainties about the future, non-stationarity, and complexity in desired social-ecological systems. To illustrate, we first define AM and SP and then present a framework for IS by highlighting experience we gained integrating green infrastructure into cities and managing for multiple ecosystem services (Green et al. 2016).

ADAPTIVE MANAGEMENT: SUITABILITY AND LIMITATIONS

Adaptive management (Holling 1978) is a structured, iterative process designed to feed information, e.g., monitoring data, back into the management process at decision points in order to reduce

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uncertainty and improve management over time, i.e., learn (Williams 2011). Adaptive management was put into practice to test green infrastructure (GI) performance and thereby guide GI use in Cleveland, Ohio. Cleveland, like many older cities in the Midwestern U.S., uses a combined sewer-stormwater collection system. When the collection system overflows during wet weather events, e.g., storms, snow melt, the combined sewer-stormwater collection system releases untreated sewage (billions of gallons annually) into Cleveland waterbodies in violation of water quality requirements of the U.S. Clean Water Act (CWA). Cleveland is under federal legal mandate to reduce untreated sewage releases and, at the same time, has experienced great population loss (Chaffin et al. 2016). Associated with this population loss is social, political, and economic reorganization of the city through real estate abandonment and demolition of vacant buildings, which has created neighborhoods with high concentrations of vacant lots. Cleveland negotiated a consent decree with the U.S. Environmental Protection Agency to meet their sewage release reduction requirements by incorporating green infrastructure, i.e., functions provided by ecological components, with gray infrastructure to reduce stormwater flows to the combined collection systems, thereby mitigating untreated sewage overflows (Shuster and Garmestani 2015).

An adaptive management plan integrating green infrastructure into the existing sewage infrastructure was developed for Cleveland. The project centered on the Slavic Village neighborhood, a historic neighborhood in the city that had suffered tremendous socio-political change and, after the mortgage crash of 2008, was deemed “ground zero” for this crisis in the U. S. (Shuster and Garmestani 2015). Slavic Village was characterized by an abundance of vacant lots as well as social capital in the form of engaged, motivated partners for the work, e.g., Slavic Village Development Corporation, NEORSD. The project was initially designed as a GI test case involving the use of rain gardens in an active adaptive management application, with reduction of water flow into the combined sewers as the goal. The project evolved and more partners became involved, a critical aspect for sound governance of social-ecological systems (Green et al. 2016). Project partners brought specific goals (mandates and requirements from funding sources) to the project. These goals revolved around multiple ecosystem services, including aesthetics, green space, pollinators, beneficial arthropods, and plant-soil interactions (Schifman et al. 2017). Over time, it became clear that maintaining a singular focus on stormwater management was untenable, and thus the focus shifted to governing this urban ecosystem for multiple ecosystem services (Chaffin et al. 2016). This shift in focus added complexity and uncertainty to the original research program, and reduced controllability of possible management interventions given consideration of broader ecological and societal objectives and concerns. Because of this shift in the project, implementation changed to a scenario-based approach (high uncertainty and low controllability).

SCENARIO PLANNING: SUITABILITY AND LIMITATIONS

Scenario planning in its contemporary form was initially conceived in the 1960s by planners at the multinational petrochemical services conglomerate, Royal Dutch Shell plc (Wack 1985). The Shell style of scenario planning created alternative futures, i.e., plausible scenarios, for how things might develop in a way that is different from either the current situation or through a business-as-usual approach. Shell-style scenario planning has been adopted for the management of SES in which social and environmental drivers are identified, plausible qualitative narratives are constructed based on different paths taken to the future, and evaluation of scenarios ideally informs which actions to pursue to realize a desired scenario (e.g., Peterson et al. 2003, Sala et al. 2005, Allington et al. 2018, Iwaniec et al. 2020).

In Cleveland, learning about green infrastructure performance on vacant lots was motivated by de facto scenario planning. Specifically, by negotiating a plan to meet CWA mandates, Cleveland set an overarching vision for the future of sewer and stormwater management and urban land use in high vacancy neighborhoods. That vision was to mitigate combined sewer-stormwater overflows by integrating GI into land use (NEORSD 2012). Green infrastructure for managing stormwater flows represents a sharp break with historic practice and land use objectives in Cleveland. Therefore, the new vision required an extensive effort to determine the green infrastructure requirements necessary to meet CWA-mandated sewer overflow reductions, identify the stakeholders and partners (e.g., residents, regulated utility, non-governmental special interest organizations, for-profit and not-for-profit developers), and assess the types of green infrastructure that would be amenable to goals and desires of these numerous stakeholders. Traditional adaptive management was not enough for the translation of a broad vision into effective practices, nor were traditional scenario approaches.

SITUATING ITERATIVE SCENARIOS: SCOPE, UNCERTAINTY, CONTROLLABILITY, ITERATION

Both AM and SP are management approaches for SESs well-suited to particular contexts, but both are constrained such that gaps in management needs arise. Scenario planning lacks an iterative process and, therefore, is not structured for learning. Scenario planning, though, is effective where lack of controllability, due to complexity, non-stationarity, and the nature of the uncertainties, precludes active learning. Where it is reasonable to experimentally learn how to manage natural resources for desirable outcomes, adaptive management is the best approach; however, as previously discussed, AM is best suited for SES problems with low uncertainty and high controllability. There also exist management contexts where learning is necessary and outcomes are controllable through means available to the actors, but what is a desirable outcome is not certain and may be different in the future because of changing human values. The limitations of both approaches leave open questions regarding managing situations with high uncertainty about whether a management action will lead to desired outcomes or have unintended consequences, the desired benefits are numerous and cannot fully be accounted for within the managed system, and it is difficult to assess and account for the social implications around the natural resource management action. To remove these limitations, we introduce iterative scenarios as a method that integrates the strengths of scenario planning and adaptive management.

Iterative scenarios is a hybridization of the scopes, relationships to uncertainty, and controllability of AM and SP with the iterative characteristics of AM and the “futures” of SP (Table 1). Adaptive management uses learning to inform its core scope of achieving

Table 1. Iterative scenarios combines aspects of adaptive management and scenario planning into a new management approach.

	Adaptive Management	Scenario Planning	Iterative Scenarios
Scope	Concerned with achieving or maintaining a system state for a desired natural resource outcome	Visioning futures that differ substantially and are concerned with multiple aspects of social and ecological systems	Concerned with achieving and maintaining multiple benefits from a natural resource system given the potential for multiple substantially different futures
Uncertainty	High; the uncertainty is reducible through active learning that can be carried out by the involved actors	High; the uncertainty is irreducible through actions available to the involved actors	High; the uncertainty has both reducible and irreducible components
Controllability	Exists; system states can be navigated with management options available to the involved actors	Lacking; key controls on the system state of interest are not readily available to the involved actors	Mixed; system states are technically navigable through management options available to the involved actors but the desirability of and capacity to manage for a state are not known
Iterativeness	Active learning feedbacks to inform management practices	New scenarios are constructed as social-ecological contexts evolve	Active learning informs effective management strategies given a range of possible futures; refines learning objectives in response to both prior learning and evolving social-ecological contexts

or maintaining a system state for a desired natural resource outcome (e.g., improved water quality). Scenario planning is concerned with visioning futures, ideally a set of three to five futures with major differences, that deal with numerous aspects of social and ecological systems at multiple spatial, temporal, and organizational scales. Iterative scenarios integrates the scopes of AM and SP and focuses on managing for multiple benefits from a natural resource system given the potential for multiple and substantively different futures. Active learning in IS occurs at the scale at which IS informs management and where the actors involved in the process can affect management.

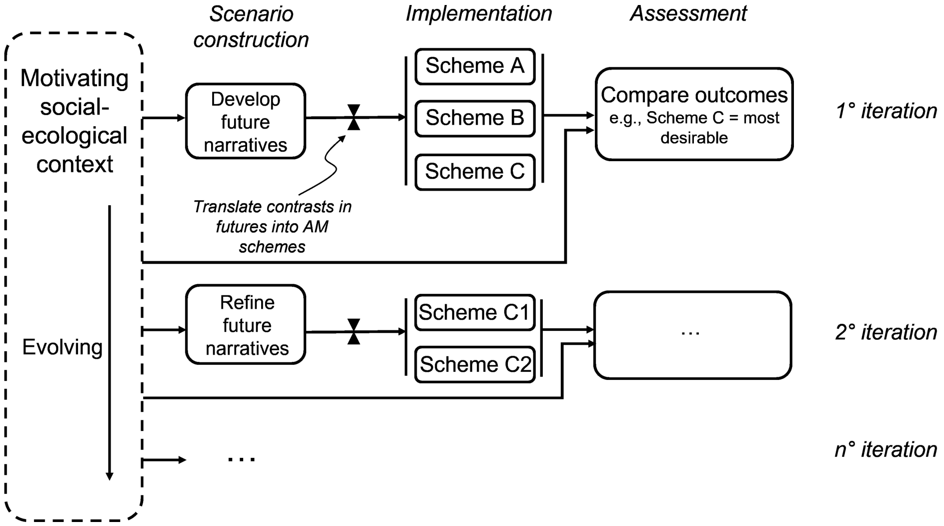
Scenario planning and adaptive management are both appropriate in situations of high uncertainty; however, in classic framings, they differ in how they deal with uncertainty (Table 1). Adaptive management specifically seeks to learn about how systems function. Thus, adaptive management considers at least some management uncertainty reducible and contends that reducing uncertainty and learning improves management outcomes. Adaptive management is carried out within the reality that irreducible uncertainty exists but can be accommodated with greater knowledge about what is reducible. Scenario planning, in contrast, creates future scenarios because of the existence of irreducible uncertainties. Scenario planning, then, contrasts with adaptive management because it seeks to identify strategies given persistent uncertainty.

Iterative scenarios, also designed for situations with high uncertainty, adopts strategies for learning about reducible uncertainties within substantively different visions of the future constructed around key irreducible uncertainties. To accomplish this, IS must translate future visions that consider irreducible uncertainty about how an SES will evolve into tangible management practices that are important and accessible to the involved actors. Reducible uncertainties can be tested through active learning such that knowledge to manage across a range of possible futures is generated.

Controllability is the capacity of actors to manage the general state of a system and is a defining feature that contrasts AM and SP (Table 1). Scenario planning considers situations where important controls on the system of interest are not available to the actors involved. This lack of controllability can be ecological (e.g., controlled at a scale beyond the influence of the actors, such as climate) or social (e.g., authority to manage critical aspects is not held by the involved actors, such as a community group desiring land uses that violate municipal land use policy). In contrast, adaptive management is premised on the idea that managers can affect the state of resources in the system of interest via management interventions. Iterative scenarios explicitly consider controllable and non-controllable aspects of a system of interest (Table 1) and are appropriate for SESs that are technically manipulable in order to achieve and maintain a desired state, but for which what state is desirable and supported is not controllable. Iterative scenarios expands AM to what is not readily controlled by considering what management actions are possible to control a system of interest given alternative futures. For example, scenarios can envision different societal preferences in the future that would impact how we manage a controllable resource, while those preferences and how they are managed are not controllable.

A core feature of effective management given uncertainty is the capacity for adaptation as contexts and understandings evolve (Levin 1999, Angeler et al. 2020a). Thus, whether a management regime employs a structured, iterative framework is critical. A hallmark of AM is that active learning reduces uncertainty and feedbacks into the AM process to inform subsequent management actions (Table 1). Through subsequent iterations, AM can reduce uncertainty at increasingly finer system details (Uden et al. 2015). Scenario planning does not require an iterative process, but sustained scenario planning engagements accommodate iterative practices, both proactive and reactive (Butler et al. 2020). Proactively, the assumptions and plausibility of constructed scenarios can be assessed and findings used to refine scenarios (Allington et al. 2018). Methods for this process include stakeholder surveys and systems modeling. Reactively, scenarios can be reconsidered as the social-ecological contexts out of which they were conceived evolve (Kok et al. 2017). Iterative scenarios applies the iteration of AM as well as that of SP. Specifically, IS engages in active learning about how a system works and refines learning objectives given both lessons from prior learning and feedback from evolving social-ecological contexts.

Fig. 1. Graphic representation of the process for carrying out iterative scenarios. The initial phase is scenario construction that develops future narratives based around key uncertainties around what will be desirable and plausible in the future for the system being managed and the greater motivating social-ecological context. The first iteration (1°) involves consideration of major contrasts about how the future will unfold and what will be desirable and plausible. A critical next step is translating these future narratives into testable adaptive management (AM) schemes (represented by the hourglass symbol) that seek to learn about natural resource functioning as it will be necessary to inform multiple future management needs. Several schemes are implemented and tested simultaneously (ideally) in a horse-race style that will inform management for different social-ecological futures. Assessment phase is next, which involves the selection of the most desirable scheme based on learning about their performance and consideration of evolving motivating social-ecological context. The most desirable scheme emerges as a broad vision that will likely require further learning about uncertainties in social-ecological futures. Thus, the process is iterated starting with refined future narratives constructed around the most desirable scheme from the previous iteration and again considering further evolution in the motivating context. Alternatively, shifts in the motivating social-ecological context, e.g., a high-level policy change, could result in refining and further testing a previously less desirable scheme. The number of schemes to test at the implementation phase across iterations is dependent on the goals and capacities of the actors and their system's complexity. The scenario construction-implementation-assessment process is iterated indefinitely, adjusting to the evolving contexts and continual refinement of uncertainties to be resolved. Ellipses graphically represent the ongoing management decisions and actions and the subsequent iteration of the process.



THE ITERATIVE SCENARIOS PROCESS

Given this understanding, we can build the implementation framework of iterative scenarios (Fig. 1): a structured process for iterative management that accounts for multiple or cross-scale objectives that do not permit straightforward assessment, accommodates social uncertainty and non-stationarity, and informs an orthogonal set of possible futures that are not controllable. The basis of the implementation is built off an idealized active adaptive management scheme, the horse race (Allen et al. 2011). The horse race is characterized by multiple experimental management interventions that are implemented and monitored at the same time; in this case, management interventions compete against each other in real time, a "horse race." By having directly comparable management interventions, learning is based on a high degree of inference. In a traditional adaptive management scheme, each experimental setup would seek to understand a key uncertainty affecting a target variable, e.g., abundance of a species, water storage, while possibly tracking non-target variables to evaluate co-arising features. The "winner" of the horse race is the setup that achieves the most desirable levels of the target variable or can maintain a system in a desirable natural resource state. The lessons learned to achieve that outcome are incorporated into policy and management going forward.

The iterative scenarios approach starts with a future visioning that creates scenarios about what conditions will be relevant to management of the SES (Fig. 1). In constructing scenarios, narratives about the future identify key factors that are not controllable, but that will affect what management outcomes will be desirable and supported. Scenarios are then translated into management schemes. These schemes are designed to be implemented and evaluated to increase learning about system functions to inform management. Schemes in this case must meet a few criteria. They should: (1) be managed on a spatial scale available to the actors involved and their planned actions; (2) involve evaluations over time scales finer than the longer term objectives being informed; (3) be concerned with a suite of outcomes, such as multiple ecosystem services, and how they are realized across spatial and temporal scales; and (4) be informative for a set of plausible futures. Criteria 1 and 2 ground the schemes in adaptive management's main objective: learning through structured experimentation. These criteria contrast with what is considered for scenario planning, where key controls are not available to the actors. Schemes for adaptive management should consider complexity not traditionally accommodated in adaptive management schemes, i.e., criteria 3 and 4, but the schemes must be tied to specific controllable and testable management actions. Criterion 3 situates adaptive management as addressing the complexity faced by managers when addressing real-world problems and opportunities, namely providing multiple benefits as a target outcome, navigating trade-offs, and leveraging or mitigating cross-scale interactions. Criterion 4 instructs scheme designs to consider social uncertainty and non-stationarity by designing future-minded testable schemes. Social uncertainty means what is desirable in the future could be different than what it is now, or that what is possible evolves. Non-stationarity means that baseline conditions—social or ecological—shift. Hence, being future minded regarding social uncertainty and non-stationarity requires the scheme design and implementation phase to first engage in the practice of identifying plausible futures, as they would impact societal needs from the system being evaluated through an adaptive approach.

Implementation of the testable schemes through resource management actions is standard to a process based upon adaptive management. In standard adaptive management, the outcome for a target variable is centered in the evaluation of management actions, and the management scheme that worked best for that target without producing unsuitable complementary effects is considered the "winner" (e.g., Scheme C, Fig. 1). In iterative scenarios schemes, assessment includes evaluating multiple outcomes of interest against contrasting management regimes, where the outcomes may be the same, different, or a mix. Importantly, this assessment also considers how the social-ecological context that motivates the process has evolved (Fig. 1). Specifically, how has the future been realized, or how have plausible futures changed? In this way, scheme assessments consider changes to prior social uncertainties and observed non-stationarity since schemes were initially developed.

After assessments are complete, a scheme to pursue must be selected akin to the "winner" in the traditional adaptive management horse race scheme. Outcomes are likely not binary—successful or unsuccessful—given the complexity of the system that is being managed and multiple evaluation criteria of the scenario schemes. With the information gathered, present conditions, and expectations for the future among the decision makers at the decision point, schemes can be evaluated as satisfactory or unsatisfactory, i.e., did or did not create a desirable outcome, and the relative degree of desirability in the satisfactory schemes. A scheme that is contemporarily satisfactory and highly desirable would be selected for informing further management actions. However, evolving social objectives, observed shifts from the predicted future, i.e., non-stationarity, or new contexts may mean that the other schemes become relatively more desirable. Thus, each scheme can result in learning that may be useful beyond the present activity.

Initial schemes test highly contrasting scenarios to indicate a desirable trajectory for the social-ecological system. To navigate toward desired futures, a structured, iterative process is essential for IS and learning about SESs. This is because otherwise, the process falls into the trap of moving toward stationary endpoints and spurious certitude (Fig. 1). Iterations are a deeper exploration of a specific favored scenario accomplished by: (1) developing more refined narratives about a scenario for the SES that exist within a desired scheme from a previous iteration, (2) benefiting from previous iteration leading to learning about the SES, and (3) considering how the broader social-ecological system has evolved (Fig. 1).

EXAMPLE CASE: TESTING DIVERGENT GREEN INFRASTRUCTURE SCHEMES IN CLEVELAND, OHIO, U.S.

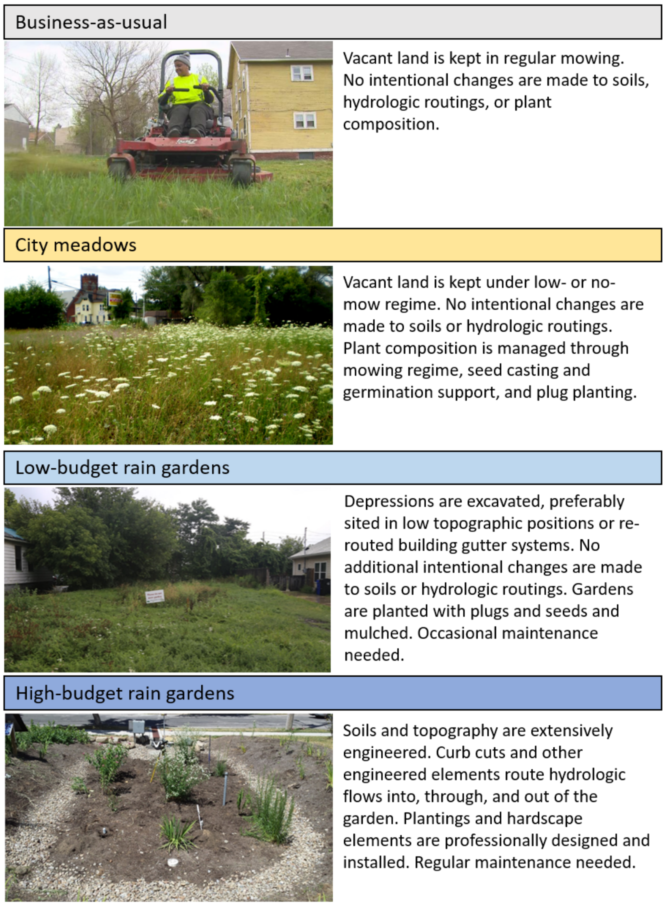
The motivation to develop the iterative scenarios approach for managing SESs arose out of lessons learned from traditional adaptive management and complementary experimental learning around greening urban vacant lots in Cleveland, Ohio, U.S. (Shuster and Garmestani 2015, Green et al. 2016, Herrmann et al. 2016a,b, Chaffin et al. 2016). Here, we assess actual activities during the Slavic Village project in Cleveland with our re-envisioned approach employing iterative scenarios.

The example presented here is an ideal proof of concept for iterative scenarios because it has controllable and testable outcomes of a natural resource management program nested with social-ecological complexities arising from re-imagining urban spaces. Further, there is concomitant social uncertainty about what would be desirable and about newly forming and dynamic resource management partnerships, among other sources of complexity, that arose as the vision setting and resource management were navigated.

Stakeholders' translations of Cleveland's green infrastructure vision into specific and implementable green infrastructures coalesced around four distinct management schemes that corresponded with a scenario or narrative about the future of the neighborhood and the type of green infrastructure implemented in this future. Importantly, each one of these schemes required testing to see how well it achieved the objective of mitigating stormwater runoff into the combined sewer-stormwater collection system. Simultaneously, each also required testing to examine the accompanying suite of outcomes, including ecosystem services, that was of interest in each scheme. Criteria 1 and 2 of iterative scenarios was met in a common manner for all schemes. Each scheme would be implemented on only a few vacant lots out of the hundreds of existing vacant lots and monitored over one to two years, providing time to scale up implementation and meet the terms of the consent decree over its established timeline for achieving compliance. Criteria 3 and 4 are addressed uniquely in each of the schemes.

The four emergent schemes were: (1) business-as-usual, (2) city meadows, (3) low-budget rain gardens, and (4) high-budget rain gardens (Fig. 2). Schemes did not emerge based on key uncertainties in resource functioning as is standard recommended practice for adaptive management. Instead, the schemes were differentiated akin to scenario planning based on what would be desirable and possible in the future, which was not controllable through adaptive management. Two main axes of uncontrollable futures were explored. The first axis was more traditional, i.e., in the historical, local landscaping vernacular: manicured vs more ecological or naturalized, i.e., wild appearance, landscapes. Would communities in the future support ecological landscapes, or would these landscapes be considered undesirable? The second axis was about the level of reworking/engineering of the soil and plant system and maintenance, generally realized as a financial cost, i.e., inexpensive vs expensive. Thus, would highly capitalized practices and the formalized institutions to realize them be a part of green infrastructure planning and implementation in the future, or would minimal intervention, small budget operations be relied on? In addition to being prepared for these unknown futures, each of the schemes would be monitored both for their cross-scale contributions to stormwater runoff mitigation and accompanying ecosystem services or disservices specific to each scenario scheme. Collectively, futures are informed by new understanding gained through monitoring of the schemes, exercises to extend this monitoring data to a more comprehensive quantitative and qualitative diagnosis of a scheme's desirability, and, finally, the fiscal and institutional arrangements that emerge as durable for facilitating planning and implementation of desirable green infrastructures. e.g., urban agriculture (Herrmann et al. 2018).

Fig. 2. Four scenarios—Business-as-usual, City meadows, Low-budget rain gardens, and High-budget rain gardens—were schemed for a vacant land management program intended to identify desirable green infrastructure strategies in Cleveland.



Vacant land is kept in regular mowing. No intentional changes are made to soils, hydrologic routings, or plant composition.

Vacant land is kept under low- or no-mow regime. No intentional changes are made to soils or hydrologic routings. Plant composition is managed through mowing regime, seed casting and germination support, and plug planting.

Depressions are excavated, preferably sited in low topographic positions or re-routed building gutter systems. No additional intentional changes are made to soils or hydrologic routings. Gardens are planted with plugs and seeds and mulched. Occasional maintenance needed.

Soils and topography are extensively engineered. Curb cuts and other engineered elements route hydrologic flows into, through, and out of the garden. Plantings and hardscape elements are professionally designed and installed. Regular maintenance needed.

Understanding each of the schemes (Fig. 1) requires a social-ecological narrative. Those narratives, coupled with the biophysical conditions, management requirements, and suite of ecosystem services and trade-offs, are presented below.

Business-as-usual

Business-as-usual anticipates a future in which social and political forces restrict vacant lot transformation in favor of a low-cost, traditional landscape and its associated management regime. The standard practice for managing vacant lots is regular mowing to maintain the property as a grassy lawn. The landscape it creates mimics the traditional landscapes of the neighborhood. Thus, it is generally socially acceptable. It also maintains the property in a manner suitable for economic development, which makes it politically amenable to the current Rust Belt governance paradigm of neoliberal city remaking (Hackworth 2019). Thus, its non-hydrologic, cross-scale benefits are its role as an urban ecosystem that attracts or does not constrain potential redevelopment on vacant lots to contribute to regional economic activity. Ecologically, regular mowed lawns do not support a rich plant community or habitat for wildlife. Mowed vacant lots do have the capacity to infiltrate stormwater runoff, but soil disturbance and replacement from urbanization practices, including recent building demolitions, mean that the capacity for these soils to absorb stormwater is not accurately predicted by standard models (Herrmann et al. 2017, Schifman and Shuster 2019, Stewart et al. 2019). Monitoring of hydrology in a few vacant lots will inform the degree to which keeping vacant lots in regular mowing can contribute to the cross-scale objective of stormwater detention to prevent combined sewer-stormwater overflows.

City meadow

City meadow prepares for a future in which extensive prairie-like naturalized landscapes are embraced within the urban matrix. City meadow implementation includes introducing new plants to vacant lots through seeding, plugs, or volunteer recruitment facilitated by the reduction of mowing frequency. Minimal site reworking and low maintenance regimes means the meadows are generally inexpensive; however, they are relatively wild in appearance, marking a noted departure from domestic landscaping under visually apparent care traditionally considered an indicator of safe and inviting urban landscapes (Nassauer et al. 2009). Major anticipated benefits of the transformation of vacant lots into meadows are realized at landscape to global levels achieved through their potential roles as wildlife habitat, e.g., node in pollinator network, and in soil development, e.g., carbon storage. In Cleveland, a university interested in experimentally testing biodiversity support provided by urban meadows was the key partner in including this scenario scheme in the adaptive management portfolio. Stormwater detention is limited by urban legacy on the soil and the meadow's hydrologic position in the landscape. However, it may improve stormwater management for reduced sewer overflows over business-as-usual through greater interception and slowdown of precipitation, increasing water infiltration capacity at the soil surface, and higher water losses through evapotranspiration.

Low-budget rain garden

Low-budget rain garden anticipates a future in which rain gardens are used to manage stormwater because of their spatial efficiency in stormwater detention, but the practice is supported through a mix of partnerships with very limited funding dedicated for stormwater management specifically. As a result of mixed partnerships, the desired complementary, i.e., non-stormwater management, outcomes are heterogeneous across gardens in the watershed and dynamic in response to shifting partners and their interests. For instance, rain garden installations, led by the Cleveland Botanical Garden with an interest in emergent watershed health broadly, also had the complementary objective of growing native plants for regional natural history conservation objectives (Chaffin et al. 2016). In the absence of major and dedicated funding for the rain gardens, the installations are necessarily basic. In our case in Cleveland, small depressions were dug and, insofar as possible, sited to take advantage of existing hydrologic routing to intercept overland stormwater flow. Engineered soils and hydrologic connections and aesthetically minded landscape architecture designs and management regimes were not used. In many cases, low-budget rain gardens will appear wild and unkempt, requiring neighborhood support for what historically might be perceived as uninviting or even dangerous and symbolic of neglect.

High-budget rain garden

High-budget rain garden anticipates a future of dedicated fiscal and formal institutional support for rain gardens to create them as designed, engineered, and maintained long-term green infrastructure and community assets. High-budget rain garden integrates hydrological routing, soil shaping and replacement, and an ecological but designed rather than wild appearance that is maintained regularly. As such, it requires substantial initial capital investment and dedicated long-term investment for its upkeep. In our Cleveland case, the public utility charged with sewer and stormwater management invested user fees to build a few high-budget rain gardens. The high-budget rain garden is expected to provide the greatest levels of spatial intensity for detaining stormwater and simultaneously be a desirable community asset either as a park space or generally visually inviting feature. Monitoring and other evaluation determines its comparative performance, and this performance can be considered in the future when support or lack of support for applying user fees to such green infrastructure projects is better known. Important to these determinations is how broader implementation would lead to desired social outcomes for the neighborhood.

Based upon biophysical performance and changes in what was socially and politically feasible, the group of researchers concluded that low-budget rain gardens was the most successful outcome in these two regards (Chaffin et al. 2016). Therefore, in the next phase of the iterative scenarios process, low-budget rain gardens would be the scenario selected moving forward, and subsequent iterations of the IS process would center on low-budget rain gardens. Variations of low-budget rain gardens would be tested in a structured, iterative process that would provide feedback to stakeholders and allow for learning (Fig. 1). Low-budget rain gardens would be iteratively tested for biophysical capacities of differing placements in the catchment and their degree of connectivity to downspouts and street gutters, while exploring futures about which groups would be involved and what landscaping schemes and policies would support these groups' goals (Fig. 1). However, major changes in the motivating context could shift the desired scheme to refine. For example, changes in plans and policies at the public utility for sewer and stormwater management could greatly influence the most desirable schemes to pursue. Such a change could be plans to install separated storm and sewer collection systems or a larger capacity combined sewer system. This would reduce the desirability of rain gardens relative to less spatially intensive stormwater management schemes, particularly city meadows.

CONCLUSIONS

In this paper, we have introduced iterative scenarios for managing SESs and demonstrated the utility of the approach with an example of managing green infrastructure implementation in a city. The impetus for developing iterative scenarios arose from the challenges encountered in applying adaptive management and scenario planning in a nearly 10-year study of green infrastructure implementation and urban transformation in Cleveland, Ohio, and the more general need to understand management-coercing social-ecological system regimes for achieving sustainability (Angeler et al. 2020b). Iterative scenarios were developed to address some of the limitations associated with adaptive management and scenario planning. Also, it is important to make clear that iterative scenarios is not limited to the case presented here. For example, a large team of researchers recently undertook an ambitious project that engaged stakeholders in multiple cities globally in scenario planning for visionary, yet plausible urban futures for their city (Iwaniec et al. 2020). A recurrent issue in navigating toward a desired future scenario was having to address more immediate needs that would lead to further lock-in to undesirable past pathways (Cook et al. 2021). Iterative scenarios can be used to test options for troubleshooting short-term problems that are designed and evaluated based on how the solution guides the SES toward a desired future scenario. Climate change is an example of an all-encompassing motivator and lends urgency to the widespread adoption of IS in SES management. Managers must learn how their system works given multiple ongoing and potentially sudden changes in environmental controls responding to global drivers, and they do so amid irreducible uncertainty in how governance of climate change will unfold at local to planetary scales.

The complexity of social-ecological systems and the increasing demand to derive multiple ecosystem services from managed resources limit the application of adaptive management and scenario planning in many real-world cases. Iterative scenarios accommodates real-world complexity faced by managers through the integration of lessons from scenario planning with adaptive management schemes. Iterative scenarios explicitly considers a range of plausible social-ecological futures but in a structured, iterative process that allows for learning about a SES through time. By adopting such a process, IS may reveal novel insight through the refinement of existing knowledge but also facilitate discovery of management options not envisioned as part of this process. Such novel options may then further seed schemes as managers strive to navigate and reconcile the many knowns and unknowns that challenge the resilience of SESs at multiple scales (Angeler et al. 2020a).

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12706

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Data Availability:

No data to report.

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