Synthesis and New Directions

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Abstract Spatial decision support systems (SDSS) are (1) customized software applications that (2) apply analytical constructs to (3) spatial data layers, (4) for the purpose of informing specific decisions and decisions makers. What is special about them is how they enable transparent decision-making processes, effectiveness monitoring, adaptive management, and making better future decisions. Custom SDSS applications can be thought of as snapshots of the logic used to make a decision. As such, they are invaluable to grounding management and its edification through learning. An SDSS clearly reveals the logic and data that decision makers use to derive their best decision to solve a specific set of problems. But at best, it represents the hypothesis—'*this is how we thought to solve these problems, given available information*'. Subsequent decisions can be informed by the portions of a decision that worked/did not work, with little effort to reconstruct the evaluation, only to adapt it. EMDS is a SDSS development tool. It was conceived for application to the decision-making process of ecosystem management because these decisions are typically complex, multi-layered, and difficult to track, once made. EMDS uses spatial data layers, and there is no real limit to the number of dimensions it can consider in decision making. Here, we summarize how EMDS has been used to date and discuss new directions for expanding its utility. We also discuss how users and applications have influenced, and continue to influence,

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EMDS development, and new versions will no doubt reflect the evolution of decision making and technology.

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1 Introduction

The first three chapters of this volume (Part I) laid out the technological foundations of the Ecosystem Management Decision Support (EMDS) system as currently implemented in v 4.2. The nine chapters that make up Part II presented a broad array of application areas in which EMDS has been applied since its first production release in 1997. In inviting submissions for this volume, we asked authors not only to present a description of their particular application, but to address two questions: (1) in what ways did EMDS work well for their purposes, and (2) in what ways might EMDS be improved to better support their application. Most contributing authors obliged, and we received valuable responses. Thus, in the first part of this final chapter, we synthesize those results, and draw general conclusions. "EMDS 5.0 and Beyond" leads off Part III of this volume, discussing new features and functionality in the upcoming EMDS v 5.0, and we add to this discussion addressing areas where further improvements can be made. The final three sections of this chapter return to broad questions about the future role of EMDS in supporting adaptive management, ecological stewardship, and aiding the advance of decision making in environmental analysis and planning.

2 Versatility of EMDS

Chapters in Part II of this volume cover the most common application areas to which EMDS has been applied since 1997, including:

1. Watershed analysis ("Use of EMDS in Conservation and Management Planning for Watersheds"),
2. Assessment of fire danger in support of forest-fuels management ("Evaluating Wildfire Hazard and Risk for Fire Management Applications"),
3. Integrity and resilience of landscapes ("The Integrated Restoration and Protection Strategy of USDA Forest Service Region 1" and "Landscape Evaluation and Restoration Planning"),
4. Conservation planning ("Forest Conservation Planning"), and

5. Wildlife habitat management ("Wildlife Habitat Management" and "Measuring Biological Sustainability via a Decision Support System: Experiences with Oregon Coast Coho Salmon").

Other, somewhat less common but promising applications presented in this volume include selection of ecological reserves ("Ecological Research Reserve Planning") and planning for urban growth ("Planning for Urban Growth and Sustainable Industrial Development"). An up-to-date list of EMDS publications by application area, and summarized in Table 1, can be found on Wikipedia.

The diversity of spatial scales and analysis topics represented by chapters in Part II, as well as the larger list of applications (Table 1), is indicative of the versatility of EMDS with respect to supporting environmental analysis and planning. As described in "An Overview o1.the Ecosystem Management Decision-Support System", this versatility has its origins in the framework approach, which has underpinned the EMDS system design and implementation from the earliest versions. EMDS provides a constellation of software systems (EMDS per se ["An Overview o1.the Ecosystem Management Decision-Support System"], as well as NetWeaver ["NetWeaver"] and Criterium DecisionPlus ["Criterium DecisionPlus"]) with which users can design spatial decision-support applications for many different kinds of problems, and at whatever spatial scale or scales are necessary. As also described in "An Overview o1.the Ecosystem Management Decision-Support System", though, there is a price to pay for this versatility, because EMDS does not come ready to run "out of the box," and EMDS complexity reflects the complexity of the issues addressed. Users not only have to provide data for an EMDS project (typical of most decision support systems), they also have to design the logic and decision models for their particular problem. From our own experience, we know that this added burden on potential users of EMDS has occasionally been an impediment to its adoption. On the other hand, from the perspective of systems engineering, there are enormous advantages to a general solution framework that can be applied to a broad array of environmental management problems.

Beyond the basic notion of versatility discussed above, sometimes versatility has been manifested in the innovative ways that application developers have used EMDS. For example, the decision-modeling component of EMDS supported by Criterium DecisionPlus[1] ("Criterium DecisionPlus") was not available until v 3.0. However, Ruiz ("Planning for Urban Growth and Sustainable Industrial Development"), using an earlier version of EMDS, combined the use of NetWeaver with the analytic hierarchy process (AHP, Saaty 1992), developing criterion weights in an external AHP system, and then integrating those weights into the NetWeaver models. This was a simple but clever approach to integrating

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the US Department of Agriculture of any product or service.

Table 1 EMDS publications by application area as reported on Wikipedia[a]

Application area	Number of publications[b]
Carbon sequestration	1
Conservation	4
Design and siting of ecological reserves	2
Ecosystem sustainability	4
Land classification	3
Landscape restoration	5
Pollution	2
Social issues in resource management	1
Soil impacts	1
Urban growth and development	2
Watershed analysis	7
Wetlands management	1
Wildlife habitat management	5
Wildland fire danger	4

[a] URL for Wikipedia site is http://en.wikipedia.org/wiki/Ecosystem_Management_Decision_Support
[b] As of 14 May 2013

logic-based reasoning and decision modeling into a single model, and represents an interesting alternative approach to that implemented in EMDS v 3.0 and later.

3 Common Themes

There were several common themes that ran through almost all chapters in Part II:

- The capability of logic-based reasoning to model large, complex, and abstract problems.
- The value of model transparency and documented reasoning in decision support systems.
- The value of fuzzy membership functions as an approach to interpreting ecosystem states and processes.

We briefly explore each of these topics in the following paragraphs.

One of the earliest and most far reaching decisions taken by the original EMDS design team was to implement logic-based reasoning in the EMDS framework as the central technique for interpreting ecosystem states and processes. As discussed at some length in "An Overview o1.the Ecosystem Management Decision-Support System", most contemporary decision support applications in environmental management are routinely confronted by large, complex, and often abstract modeling problems, for which logic-based reasoning was an effective solution. Commentaries in all chapters in Part II seem to bear this out when discussing what worked well. A related comment, often repeated throughout Part II, was the usefulness of an explicit logical formalism for developing a shared understanding of the elements of the problem domain, sometimes across quite disparate disciplines. In other words, the design and implementation of logic models often facilitated common language development, more effective communication, and interdisciplinary reasoning, or more precisely, integrated reasoning.

Two other closely related common themes across Part II were the value of transparency in communicating results to others and the value of logic and decision models as tools for documenting the underlying reasoning of the decision support application. With respect to transparency in particular, there can be significant practical differences between logic and decision models. Multi-criteria decision model systems such as Criterium DecisionPlus ("Criterium DecisionPlus") implement a simple hierarchical structure that is easy to grasp by scientists, planners, and stakeholders and others not directly involved in development of an application. In contrast, the structure of logic models built with NetWeaver ("NetWeaver") can vary from simple to highly complex, depending on the complexity and abstractness of the states and processes modeled. NetWeaver's graphical interface for tracing the derivation of model results certainly supports model transparency, but this is not to say that there may not be challenges associated with explaining a complex logic model to non-modelers, as Gordon aptly describes in "Use of EMDS in Conservation and Management Planning for Watersheds".

"An Overview o1.the Ecosystem Management Decision-Support System" and "NetWeaver" described the potential value of fuzzy membership functions as a tool for interpreting ecosystem states and processes. "Criterium DecisionPlus" similarly discussed the analogous role and usefulness of utility functions in the context of multi-criteria decision models. Whether in the context of logic or decision model development, these functions may be used to define reference conditions that provide a rational basis for interpreting the meaning of model input data. Looking across the array of applications in Part II, these reference conditions can be developed in a variety of ways:

- To produce reference standards or guidelines ("The Integrated Restoration and Protection Strategy of USDA Forest Service Region 1")
- To show the rarity of an outcome or condition relative to a sampled data range ("Use of EMDS in Conservation and Management Planning for Watersheds", "Evaluating Wildfire Hazard and Risk for Fire Management Applications", "Landscape Evaluation and Restoration Planning" and "Forest Conservation Planning")
- To reference biologically relevant values ("Wildlife Habitat Management")
- Or to ground expert judgment or Delphic knowledge extraction processes ("Planning for Urban Growth and Sustainable Industrial Development" and "Measuring Biological Sustainability via a Decision Support System: Experiences with Oregon Coast Coho Salmon").

For purposes of planning and directing management, all federal natural resource management organizations develop standards and guidelines (S&Gs) for (1) prescribing and maintaining suitable terrestrial and aquatic ecosystem states and processes and (2) for environmental protection consistent with trust responsibilities associated with public land management (NEPA 1969). S&Gs are normative because they are generally derived from the collective knowledge and experience of subject-matter experts. In addition, regulatory agencies such as the U.S. Environmental Protection Agency (EPA) and the Council on Environmental Quality (CEQ) commonly circulate regulatory requirements that can be used as a basis for defining reference conditions (Reynolds et al. 2000).

In the absence of well-established S&Gs or regulatory requirements, using the range of input data can be a practical alternative for deriving reference conditions for use in spatial decision support systems (SDSS). This approach works best when the assessment area (e.g., a region or an entire country) and sample sizes are very large (contain hundreds to thousands of observations), so that the reference range for any specific data input is likely to express the full range of system response. Likewise, when reference ranges stem from large databases, the relativized nature of transformed data is of less concern. In fact, for some DSS applications, use of relativized data may not be an issue at all (but see "Wildlife Habitat Management" for a contrary example).

When reference conditions cannot be suitably defined using the first two approaches discussed, their specification can become more challenging for DSS developers. In some cases, biologically relevant values might be gleaned from the scientific literature, but, failing that, there may be no recourse but to resort to reliance on expert judgment. Fortunately, methods for extracting, testing, and using expert knowledge in DSS applications are steadily becoming more rigorous (see Perera et al. 2012). In this context, EMDS can be used when novel ecosystems (*sensu* Hobbs et al. 2006) emerge and *ecosystem stewardship* (Chapin et al. 2009; see Sect. 7) is applied.

Regardless of the method used to define reference conditions, most chapters in Part II agreed with the basic premise, that use of reference conditions to define *degrees* of acceptability or suitability was consistent with the way subject-matter experts provide explicit reasoning about environmental conditions.

4 Enhancements in EMDS v 5.0

The implementation of EMDS v 5.0 adds many new features to the system, including automated report generation and the ability to perform analyses on raster data ("EMDS 5.0 and Beyond"). Some of the most important enhancements focus on improving extensibility and automation of the system, including the abilities to:

1. Easily add new services to the system architecture (e.g., Netica®, VisiRule®),
2. Implement workflows that automate data processing, and
3. Implement workflows that support alternative DSS processes.

Table 2 New EMDS features requested by chapter

Chapter	Issue	Requested feature	EMDS v 5.0 support
4	Automation	Methods to summarize data across scales of assessment	Workflow[a]
4	Automation	Methods to evaluate change in distributions of outcomes across assessments	Workflow
6	Automation	Analysis of multiple weather scenarios for evaluating fire danger	Workflow
6	Uncertainty (automation)	Run multiple alternative models, logic and decision	Workflow
7	Automation	Evaluate multiple spatial realizations under alternative management strategies	Workflow
7	Uncertainty (automation)	Run multiple alternative climate scenarios	Workflow
10	Automation	Evaluation over time series with multiple management strategies	Workflow
10	Spatial analysis	Raster processing	Raster support
10	Reporting	Package and share results with experts, managers and other stakeholders	Report generator
10	Uncertainty (automation)	Assess variability in parameters of fuzzy membership functions	Workflow

[a] Indicates that the requested feature can be implemented with user-designed workflows in the EMDS workflow editor

As we mentioned in the chapter introduction, we asked authors to comment on ways in which EMDS could have better supported their analyses. We summarized the most significant responses by chapter in Table 2, and one can see that most of the comments are requests for various automation upgrades. This was much expected; once end-users become familiar with the advantages associated with implementing a relatively new technology, the need for system upgrades usually exceeds the budget and timeliness of upgrading. Note that even in cases where the primary issue was described in terms of handling uncertainty, the underlying issue was about automation. Table 2 also shows the EMDS v 5.0 features that will provide the requested functionality. Although it is foolhardy to suppose that workflows can solve all automation problems, we believe that all automation requests specifically identified in the table can be satisfactorily addressed through the design of workflows in the EMDS workflow editor. In fact, to give readers some sense of the power of workflows in the EMDS context, the system *itself* has been built from the ground up with workflows. Toward designing automated workflows in the EMDS workflow editor, the EMDS development team anticipates developing a core of generic workflows, similar to those identified in Table 2, as a resource for system developers. They also envision that workflow libraries will be developed by third parties and shared within the user community through an open access workflow library, possibly maintained by the EMDS Consortium. Details are yet to be worked out, but stay tuned. In our experience, there is already ample precedent for sharing of EMDS workflows within the existing user community. Note also the near infectious spread of the R open access statistic package (R Development Core Team 2011) via sharing of non-proprietary, tested (debugged) statistic code. Indeed, much of the rapid growth of R has occurred via the open access facilitated end-user community. Finally, we admit that the EMDS development team cannot begin to conceive of workflows needed to support every environmental analysis and planning effort. There are simply too many possibilities. Thus, just as with the origins of EMDS itself, the practical solution is to provide the tools with which to construct custom workflows. Additionally, more advanced end users will wish to build their own workflows because it will save time and allow them to tailor evaluations to their data and problems.

5 Supporting Adaptive Management

In the final two sections, we consider the role of EMDS in advancing decision support for environmental analysis and planning. As a foundation, we briefly revisit discussion from "An Overview o1.the Ecosystem Management Decision-Support System" concerning the role of EMDS in supporting adaptive management, and we consider new capabilities coming in v 5.0 in this light.

Adaptive management as it has been applied to land and resource planning has been described as a continuous cycle that proceeds from evaluation to planning, to implementation and monitoring, and then back to evaluation (Holling 1978; Walters 1986). Evaluation (or assessment, as it is termed in EMDS parlance) has been a cornerstone of EMDS, because establishing a baseline is the first step to obtaining a new course of action. NetWeaver was adopted for environmental assessment because ecosystems are large, complex, and challenge even the most sophisticated evaluation tools. It is for this reason that many investigators build a new model each time they wish to evaluate a sufficiently new ecological question. The virtue of logic in this context is that if one can reason about the state of a system, or how it works, then it can be modeled with logic.

In most applications described in Part II of this volume, EMDS was used to assess the current state of a system. For example, watershed condition ("Use of EMDS in Conservation and Management Planning for Watersheds"), fire danger ("Evaluating Wildfire Hazard and Risk for Fire Management Applications"), habitat suitability ("Wildlife Habitat Management"), and population viability ("Measuring Biological Sustainability via a Decision Support System: Experiences with Oregon Coast Coho Salmon") were each assessed to establish a current baseline. NetWeaver logic models can be designed to provide a point-in-time assessment, but the time frame may equally well be sometime in the past, present, and/or future. This lack of time dependence of logic-based evaluations provides a strong basis for comparing current with alternative future conditions (e.g., see "Landscape Evaluation and Restoration Planning" and references therein) and for monitoring progress on implementation, by comparing current conditions with earlier points in time (see "Use of EMDS in Conservation and Management Planning for Watersheds"). Regardless of whether the question at hand concerns selection of a strategic alternative for plan implementation or plan performance, the mechanism is essentially the same: comparing distributions of logic-based outcomes, as modeled in NetWeaver. As of EMDS v 4.2, the user performed these comparisons, but as discussed in the previous section, most of the process could be automated in v 5.0 via workflows, thus substantially extending the capabilities of EMDS to support key aspects of monitoring and adaptive management processes, even to include hypothesis testing explicitly in the chain of workflow activities.

Finally, multi-criteria decision models (MCDMs) have been integral to EMDS since v 3.0. Classically, MCDMs are used to rate and select alternatives, and a typical environmental management application would be to select among *aspatial* alternatives (Saaty 1992). However, in the spatial context of EMDS, this technology was adapted to rate landscape or ecosystem elements within Criterium DecisionPlus (CDP) framework ("Criterium DecisionPlus"). In other words, landscape elements and their combinations can be treated as spatial alternatives.

Version 5.0 will provide new possibilities for use of MCDMs within the EMDS framework. First, it will be possible to launch the Priority Analyst component on specific individual landscape elements to guide selection of *tactical* alternatives, based on properties of landscape elements. For example, depending on feature attributes such as forest-floor fuel loadings, tree crown base heights, or crown bulk densities (see "Evaluating Wildfire Hazard and Risk for Fire Management Applications"), a tactical CDP decision model might rate the suitability of various fuel-treatment options such as prescribed fire *versus* thinning in light of the fuel load or forest structural characteristics. This type of tactical analysis could then be combined with spatial prioritization currently available in EMDS to perform both strategic treatment prioritization of all landscape elements and tactical selection of treatment options for individual landscape elements. Moreover, these tactical MCDM models could be automated via workflows to run against a subset of landscape elements meeting some minimum (user specified) requirement for strategic prioritization (such as 20 % of the total forest patches or land area treated).

A more complex use of MCDMs in v 5.0 could involve the design of workflows to compare the *consequences* of implementing strategic and tactical alternatives as discussed above. As a simple example of this more complex case, let us suppose that we have an EMDS application that is designed to assess salmon habitat suitability in subwatersheds, and that recommends strategic selection of subwatersheds as well as tactical actions to take within high priority (selected) subwatersheds. The expert reasoning of fisheries biologists may suggest multiple alternative tactical approaches to salmon habitat restoration, but the reasoning is sufficiently complex that it is not immediately obvious which of the tactical approaches would have the greatest overall effectiveness. In this context, workflows could be used to simulate the effects of the alternative tactical approaches by implementing changes in the input data. Each tactical approach would have its own workflow, generating an alternative assessment set for resubmission to the NetWeaver logic model. Furthermore, a higher order workflow could be designed to (1) run each of the workflows representing the tactical implementations, and (2) perform an automated comparison of the distributions of NetWeaver outcomes across alternatives. This is an example of precisely the kind of automation to which Hessburg et al. ("Landscape Evaluation and Restoration Planning") alluded.

6 Advancing Decision Support for Environmental Analysis and Planning

6.1 Decision Support for Hierarchical NEPA Planning

The National Environmental Policy Act (NEPA 1969) was established on January 1970, after a tumultuous decade of public outcry and demonstrations over oil spills, expanding timber harvests, urban and freeway system development, shrinking wildland area, and increasing numbers of endangered species. NEPA was enacted to ensure that environmental factors were weighted equally in comparison to other factors in the land- or resource-management decision-making processes of all executive branch agencies. The Act, visionary in its depth, established a required multidisciplinary approach to considering environmental effects in decision making, and procedural requirements for preparing environmental assessments of the effects of proposed actions. The NEPA planning process of all federal projects consists of an environmental effects analysis, and includes a pertinent set of alternative actions considered, usually varying in emphasis. There are three levels of analysis that an agency may undertake to comply with the law; the needed level is usually tied to the gravity of environmental concerns surrounding a proposed action. Levels of environmental analysis (in order of increasing documentation and environmental concern) include preparing a Categorical Exclusion (CE), an Environmental Assessment (EA) and Finding of No Significant Impact (FONSI), or an Environmental Impact Statement (EIS).

In "Landscape Evaluation and Restoration Planning" of this volume, Hessburg et al. (and references therein) describe the environmental effects of 20th century management on Pacific Northwest National Forest lands. Likewise, Gordon ("Use of EMDS in Conservation and Management Planning for Watersheds"), Gordon et al. ("Wildlife Habitat Management"), and Keane et al. ("Evaluating Wildfire Hazard and Risk for Fire Management Applications") describe significant changes in Pacific Northwest aquatic and terrestrial species habitat networks and wildfire regimes, respectively, brought about by management actions on public lands. In "Landscape Evaluation and Restoration Planning", Hessburg et al. submitted that 20th century management actions had unintentionally decoupled regional and local landscape functionality by interrupting vitally important patterns and networks of forest and riverine habitats, yielding a long list of terrestrial and aquatic species on the brink, and uncharacteristically severe wildfire, insect, and disease disturbance regimes. These circumstances set the stage for a brand of hierarchal landscape planning for which EMDS is especially well designed and suited.

Suring et al. (2011) developed an 8-step screening process to address the Pacific Northwest native wildlife species for which broad-scale, coarse filter (Hunter et al. 1989) management for ecosystem diversity may be insufficient for providing conditions to sustain viable populations. They applied their screening criteria, identifying >200 species of conservation concern. They aggregated the identified species into families and groups based on habitat associations and risk factors, and selected 36 *focal species* for application in northeastern Washington State, USA. Focal species were broadly emblematic such that if adequate restoration remedies were applied, most other species of concern would sufficiently benefit; essentially acting as an affirmative version of the ‘canary in the coal mine’ model.

Lee at al. (1997), Thurow et al. (1997) and Rieman et al. (1997) make a similar case for seven native Northwest salmonids, establishing their historical and contemporary subwatershed ranges throughout the Interior Columbia River basin. Gresswell et al. (1999) and Bisson et al. (2003) provide comprehensive syntheses of the historical and contemporary roles of wildfires in fire-prone forests and how anadromous and coldwater fish likely responded, suggesting that fish in general are evolutionarily adapted to fires and their native variability, but that local populations in their current conditions may be exposed to extirpation risks with current wildfires. To protect remaining populations of native fishes and improve the connectivity and quality of their habitats, it is essential to spatially locate existing populations and habitats on the landscape and protect them, and then identify other spatially connected locations that have the inherent capability to become functional habitats, and remove barriers to connectivity. The same is true of terrestrial wildlife, a case well made by both Suring et al. (2011) and Wisdom et al. (2000).

EMDS is well suited to this task of hierarchical planning. Regional NEPA plans (Regional Plans or Guides, formerly in common usage) could be developed whose environmental analyses were grounded in a regional spatial decision support system (SDSS). A Regional SDSS could evaluate maps of existing and potential habitats, existing populations, and impediments to movement for all listed and focal species, throughout their known historical ranges, and their predicted future ranges under climate change. Regional scale analyses could consider and map preferred regional networking solutions to improve habitat connectivity and landscape permeability for each species, and hand these insights down to Forest-level NEPA Plans as regional guidance or standards.

At a second level in the SDSS, National Forests would have a subset of species for which to make specific planning provisions. Forest Plans would develop their own SDSS to jointly consider high-resolution habitat, impediment, and population maps for their subset of species. Each Forest-level SDSS could be later directly linked with the appropriate regional SDSS(s), a relatively straightforward step. Subwatersheds within Forest or logically grouped Forest boundaries could now be prioritized within the Forest SDSS for local restoration activities facilitated by

District-level project planning and landscape restoration projects of the sort described by Hessburg et al. (2013). Forests Plans could enumerate these focal species and subwatersheds and provide particular guidance concerning unique subwatershed conditions and restoration needs. In this way, regional planning guidance for improving terrestrial and aquatic species habitats becomes directly linked in analysis and planning to local District projects whose focus is to restore habitat quality and abundance, and the connectivity and permeability of terrestrial landscapes and aquatic networks.

Given this context, it takes only a little imagination to conceive how regional patterns of vulnerability to forest fuels, wildfires, insect outbreaks, disease pandemics, and major vegetation structure, composition, and fuelbed departures might be co-considered along with the foregoing in Regional, Forest, and District SDSS to provide integrated, multidisciplinary and hierarchical decision support for restoration planning, implementation, and monitoring (see above). Local landscape restoration projects, by definition, would be linked to restoring the connectivity of the regional landscape, while having the added benefit of considering locally high definition data sources and conditions, and experience. Lacking this sort of hierarchical spatial decision support, it is hard to conceive how local restoration projects would have any well-defined capacity to restore broad regional landscapes, their populations, or habitats.

6.2 Expanded Map Exploration Functionality in EMDS

Many chapters in this volume describe planning processes involving the mixed company of knowledge experts, policy analysts, knowledge engineers (people who help build SDSSs), decision makers, and stakeholders. Throughout the planning stages, maps that detail co-occurring conditions are shown and discussed, as are relevant datasets and expert opinion. NetWeaver is often used in meetings to build a rough draft of a logic model (knowledgebase). Through successive meetings, participants review their logic, and incorporate learning from discussions, new map and data evaluations, and presentations of experts. The yield of this process is often a negotiated portrayal of conditions or functionality of a focal system. The act of using NetWeaver ‘on the fly’ to develop a knowledgebase provides them with a practical understanding of their knowledgebase and, more generally, how to use NetWeaver to codify reasoning. Formally specifying a problem by means of a logic model is the job at hand; tools that speed up schematic visualization of the focal problem are key to an efficient process.

Similarly, once draft NetWeaver and CDP models are developed, these same mixed groups have a deliberate need to check and refine their work, and discover at points along the way whether their reasoning is sensible. They often do this by running the models in EMDS and evaluating their behavior, which is accomplished by visual examination of derived maps and tabular outputs, and conducting sensitivity and decision analyses in CDP.

We have observed that mixed decision making groups readily work out their differences and improve their models by examining maps and discussing particular spatial domains that match (or do not match) expectations. Indeed, most participants are involved because they come equipped with valuable benchmarks from their studies and experiences, and they apply these when fine-tuning models.

This process of model evaluation and fine-tuning could be streamlined if, at all levels in the NetWeaver and CDP models, EMDS provided a simple snapshot utility for rapid, on-screen map visualization by which multiple maps from one or more models could be viewed simultaneously side by side. Users could scrutinize and magnify individual maps, branches, and the complete hierarchy; but most importantly, they would have simultaneous visual representations of model behavior at any and all levels within the model upon which to focus discussions about model performance and revision. To some extent, this multi-map capability is available in the layout view of ArcGIS, but a dedicated custom utility would more readily support fast ad hoc map queries in a workshop environment. Maps could be printed as handouts for closer inspection or used in independent GIS evaluations, which would expand their usefulness as exploratory and performance measurement tools. This utility should be extensible to evaluating and comparing trade-offs among alternatives in CDP as well.

The need for rapid map visualization has grown out of widespread use of EMDS and represents one next step in evolution. The current lack of an expanded utility impedes some exploration of model behavior, and leaves users potentially suspicious that EMDS might exhibit an unquantifiable 'black box' influence, an age old and unnecessary concern. Present-day model builders wish to fully appreciate the consequences of the logic they apply to spatial maps and data, the role and influence of the weightings and logical operators they apply, and how these features influence the partial and final map products, and corresponding numerical evaluations. The need for developing this enhanced utility is now under discussion with the EMDS development team.

6.3 The Need for Automated Scenario Development

At a relatively early stage of SDSS development, NetWeaver model developers become aware of the primary influences on conditions or functionality of a focal ecosystem or landscape. This awareness is due to their perceptive powers and begins when spatial data layers are formatted in a GIS in preparation for NetWeaver parameterization. It continues as NetWeaver parameterization is iteratively checked and successive data layers are assembled into the model. Throughout the process, model developers get a glimpse of the primary factors driving outcomes in their NetWeaver model, and these are later confirmed by a fully operational model, with little added surprise. The same is true for CDP models as variable files are prepared, weights are applied, the Simple Multi-Attribute Rating Technique utility (SMART; Edwards 1977; Edwards and Newman 1982; Kamenetzky 1982) is implemented, and the model is tested to its completion. During model assembly, developers already are forming an idea of driving factors and their relative importance, prior to any weighting, because they are continuously learning.

In Sect. 6.2 above, we present an approach to hierarchical planning, in which key landscape restoration objectives descend from Regional to local landscape planning, enabling local landscape restoration that potentially restores the pattern and functionality of the regional landscape. Under this architecture, primary topics coming from Regional analysis drive geographic differences in Forest- and District-level planning and implementation. Geographic differences in primary topics for Forest SDSSs derive from uniquely combined species habitat connectivity concerns, disturbance regime departures, the history of restorative management, and vegetation departures, which themselves are a legacy of particular management histories and biophysical settings, varying disturbance regimes, home range differences, and the like.

It is intuitive that a core set of spatially explicit Regional, Forest or District planning scenarios[2] would emanate from overarching concerns at each planning level. In fact, the perceptions of model developers, mentioned above, derive from differences they repeatedly observe during model development. These differences could be exploited by an automated analysis routine in EMDS that provided a cross section of "starter scenarios" that build off the key departures as they were originally evaluated in NetWeaver. A range of scenarios would emphasize different key departures. Modelers already tell NetWeaver how to weight primary and secondary topics. From these weights, the key departures may be readily known. For example, if fire regime departure was significant, one scenario would highlight patches or subwatersheds (depending upon the planning level) with high departure, and give them 2:1 or 3:2 weighting preference for restoration priority. In another scenario, vegetation or wildlife habitat departures might be weighted more heavily, and these patches would be highlighted. In this way, planners at each level would have an opportunity to observe an initial range of scenarios that tie directly to key changes or departures noted in their NetWeaver models. From this initial set, planning team members responsible for different resources could further refine scenarios both spatially, in terms of the areas that are selected for emphasis, and by varying the level of emphasis. When all planning team members have accomplished refining their initial scenarios, a large range of planning alternatives will have been considered, hot spots for restoration by emphasis will be clearer, and team members will be better prepared to narrow the range of scenarios (planning alternatives in NEPA parlance) that are considered in detail.

Such a utility would be useful to planning teams and model developers. It would provide a rapid start to scenario development, and it would keep planning

[2] Here, we use the term "spatially explicit planning scenario" in a slightly different sense than EMDS scenarios as described in "An Overview o1.the Ecosystem Management Decision-Support System". In the current context, we use scenario (for short) to mean a combination of data inputs and logic outcomes that may suggest a common tactical response for planning purposes. In NEPA parlance, these scenarios might also be described as spatially explicit planning alternatives.

teams honest by reminding them to initially consider a broad set of scenarios with varied emphases, before narrowing the planning scope to a subset of scenarios considered in greater detail. The utility would, no doubt, reveal planning biases and occasionally surprise planners with useful scenarios that would otherwise not have been considered. The need for developing this enhanced utility is also under discussion with the EMDS development team.

7 Final Thoughts

One of the central goals of contemporary environmental assessment is to evaluate interactions among the environmental, social, and economic domains at several essential spatial and temporal scales, with cross-scale interactions among scales and domains, to forecast (*sensu* Clark et al. 2001) the potential effects of these interactions on broad landscape resilience (*sensu* Holling 2001; Holling and Gunderson 2002). In this context, *ecosystem stewardship*[3] (Chapin et al. 2009) has been formulated as an extension of ecosystem management (Jensen et al. 2001) to include all social-ecological systems. *Ecosystem stewardship is* an action-oriented sustainable production framework to provide ecosystem services desired by society, under various scenarios involving uncertainty and change. Current and planned versions of EMDS allow for the explicit evaluation and exposition of realistic strategies that can increase the likelihood of socially beneficial outcomes, while reducing the risk of negative outcomes. More specifically, EMDS can provide a basis to: (1) assess landscape vulnerability[4] to expected changes; (2) define and quantify direct or indirect measures of resilience[5]; (3) foster resilience to sustain desirable conditions in the face of perturbations and uncertainty; (4) identify policies and strategies to navigate undesirable trajectories through transformation[6] when opportunities occur; and (5) assess the capacity[7] to contribute to all three sustainability approaches. By building on prior vulnerability, adaptation,

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[3] Ecosystem stewardship incorporates four concepts central to framing approaches to sustainability: vulnerability, adaptability, resilience, and transformability (MA 2005; Janssen and Ostrom 2009; IPCC 2007; Jäger et al. 2007; Schneider et al. 2007; Chapin et al. 2009, 2011; Miller et al. 2010).

[4] The degree to which a system is likely to experience harm owing to exposure and sensitivity to a specified hazard or stress and its adaptive capacity to respond to that stress (Chapin et al. 2009).

[5] Capacity of a social–ecological system to absorb a spectrum of shocks or perturbations and to sustain and develop its fundamental function, structure, identity and feedbacks as a result of recovery or reorganization in a new context (Carpenter et al. 2001).

[6] Fundamental change in a social–ecological system resulting in different controls over system properties, new ways of making a living and often changes in scales of crucial feedbacks (Chapin et al. 2009).

[7] Capacity of social–ecological systems, including both their human and ecological components, to respond to, create and shape variability and change in the state of the system (Chapin et al. 2009).

resilience, and transformation research, an EMDS implementation of ecosystem stewardship planning has the potential to provide a clear analytical perspective that better equips society with managing the challenges that it confronts. In this context, the new workflow architecture of EMDS ("EMDS 5.0 and Beyond") includes looping capabilities that provide a way to automate the application of models over time steps, thus allowing for progressive feedback loops, which in turn would support the analysis of emergent system properties and the identification of critical management pathways for maintaining and restoring systems.

As you have seen from foregoing chapters, global land and water ecosystems comprise the human life support system, and ecological stewardship has always been a fundamental civic responsibility. Chapters of this volume have touched on each of the last five points, and we invite our readers to reflect further on the applications presented here, and their ecological and societal underpinnings. It is our hope that most of the best ideas for ecological stewardship and more ecologically and socially attuned management are yet to be designed, and that you will be designing them. Hopefully, it has become clear how EMDS can be useful to management planning and monitoring, for learning, and for improving stewardship of the planet.

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