INTEGRATING STUDIES IN THE MISSOURI OZARK FOREST ECOSYSTEM PROJECT: STATUS AND OUTLOOK

David Gwaze, Stephen Sheriff, John Kabrick, and Larry Vangilder[1]

Abstract.—The Missouri Ozark Forest Ecosystem Project (MOFEP), which was started in 1989 by the Missouri Department of Conservation, evaluates the effects of forest management practices (even-aged management, uneven-aged management, and no-harvest management) on upland oak-forest components in southern Missouri. MOFEP is a long-term, landscape-level, fully replicated, and multidisciplinary project. More than 30 studies have been implemented in MOFEP. Integration of ecosystem studies has been encouraged since MOFEP was initiated to better understand how different ecosystem components interact with each other. Integration ensures that resource managers also base their decisions for improving resource management on results from a multidisciplinary research process rather than from single disciplinary studies. For MOFEP, the term "integration" has not been well defined and we offer a working definition of integration to facilitate communication and mutual understanding of the term. We provide an overview of progress made thus far and discuss challenges that need to be addressed to make integration more efficient and effective.

INTRODUCTION

Initiated in 1989, the Missouri Ozark Forest Ecosystem Project (MOFEP) is a long-term, landscape-scale experiment to evaluate effects of even-aged, uneven-aged, and no-harvest management on the flora and fauna of oak ecosystems in southern Missouri (Brookshire and others 1997). The impetus for this project was the need to investigate the impacts of forest management at an operational landscape scale on neotropical migrant songbirds as well as to study other forest ecosystem components of concern at the time. MOFEP has become one of the most comprehensive ecological investigations of forest response ever undertaken in upland oak ecosystems and serves as a nationwide model for learning from large-scale manipulations of ecosystems and landscapes. MOFEP is designed to extend through more than one 100-year rotation and it is a multi-investigator experiment of management practices administered by the Missouri Department of Conservation (MDC). Studies include soil characteristics and distribution, below- and aboveground carbon, microclimate, ground flora composition, woody vegetation composition and genetic variation of selected species, coarse woody debris distribution, hard- and soft-mast production, *Armillaria* fungi distribution and ecology, forest bird density and nesting success, herpeto-faunal communities and distribution, small mammal abundance, leaf litter arthropod communities, and abundance of leaf-chewing insects. Today, MOFEP comprises more than 30 studies conducted in cooperation with many agencies and hundreds of scientists and technicians.

The MOFEP study area is located in the Current River and Peck Ranch Conservation Areas in southeastern Missouri. The study area includes nine sites, with sizes ranging from 312 to 514 ha. The management

[1]Resource Scientist (DG), Biometrician (SS), Unit Chief (LV), Missouri Department of Conservation, Resource Science Center, 1110 S. College Avenue, Columbia, MO 65201; Research Forester (JK), Northern Research Station, U.S. Forest Service, 202 Natural Resources Building, Columbia, MO 65211. DG is corresponding author: to contact, call (573) 882-9909 or email at david.gwaze@mdc.mo.gov.

practices selected for comparison, and the scale and timeframe of the study, reflect those commonly used by MDC to manage forests. Pretreatment data were collected from 1991-1995, and management treatments were applied in 1996-1997. Post-treatment data were collected after harvest. Although MOFEP has had only one entry harvest, it has provided valuable insights into how no-harvest, even-aged, and uneven-aged forest management influences plants and animals. The overall vision, guidance, oversight, and direction for MOFEP are provided by the MOFEP Steering Committee, which consists of 12 members from the major resource divisions within MDC, public institutions, and academia.

Integration has been discussed since MOFEP inception. It is clear from these discussions that the term "integration" causes a certain amount of concern and confusion among managers, researchers, and policy makers. Integration has been used in many different contexts by resource managers, scientists, and policy makers, making it difficult to know what the term means. Some view integration as something that we already practice, others believe that we have done some integration but more needs to be done, and still others believe that we have not started any integration. This variability in opinions severely limits the MOFEP Steering Committee's ability to promote the concept. It also causes confusion among scientists when they are trying to collaborate in "integrating" their data, or conduct research that is sufficiently rigorous to provide new knowledge through "integration" and truly inform managers. According to Clark and Stankey (2006), the confusion surrounding the definition of integration is not unusual unless common understanding of integration is reached. Additionally, Hall and others (1997) stress that using words that are well defined, and hence, well understood, facilitates discussion and also facilitates better public communication while minimizing confusion and ambiguity. The variable usage of the term "integration" highlights the need to clarify what integration is in order to reach a common understanding of the term. A definition is essential for facilitating mutual understanding of the term, maximizing efficiency of data collection in the field, and communicating integration needs and progress. Through effective design and analysis of studies of different ecosystem components to determine the interactions among these components, managers are supplied useful information that enables them to understand the impacts of their decisions upon the entire ecosystem. In this paper we suggest a working definition of integration, highlight progress made so far, and discuss some challenges facing integration in MOFEP.

WORKING DEFINITION OF INTEGRATION

Integration, as its name implies, is about bringing two or more things together. In ecology, integration has been defined as combining two or more different areas of understanding or their components into new understanding (Pickett and others 2007). Integration is based on the premise that ecosystem components interact and are interdependent and that no component can function without affecting the whole. Integration focuses on the whole that comprises multiple interrelationships and interactions, rather than on pieces of problems (Clark and Stankey 2006). Integration ensures that resource managers base their decisions on results from a multidisciplinary research process that examines these interrelationships and interactions rather than on single disciplinary results.

We define integration in MOFEP as meshing of data or results from different ecosystem studies across subject or disciplinary boundaries as well as at different temporal and spatial scales. Integration represents a shift from disciplinary to multidisciplinary approaches on how we report and conduct MOFEP. It is about achieving a holistic understanding of how the ecosystem responds to management and provides an opportunity to facilitate managing for multiple objectives consistent with MDC and public values and concerns. Integration should not be viewed as an end in itself, but rather a means to more effective decisionmaking and enhanced ecosystem benefits.

Integration can and should occur at many scales in MOFEP: fine-scale and broad-scale. Fine-scale represents integration at the plot or stand levels. Broad-scale integration is at a landscape level. There are two types of integration: integration by synthesis, which is usually at a broader landscape scale, and integration by analysis, which must be concerned with elements at the local scale as well as at the broad scale. Integration by synthesis does not aim to generate new primary knowledge, but instead seeks to add value to existing information by collating, evaluating, summarizing, interpreting, and communicating it in a useful form. On the other hand, integration by analyses can generate new primary knowledge through correlation and multi-variable analyses as well as through more complex modeling approaches. These analyses allow interactions (or correlations) between the different ecosystem components to be determined and better understood. These analyses may require more sophisticated and complex statistical approaches, which in turn require more rigorous planning and implementation of different sampling designs so that data are gathered in a manner that permits these analyses. Integration by synthesis and analysis are both important and their application will depend on the target audience and the integration questions.

Integration must be built around well posed questions and it must be developed by all resource managers, scientists, and policy makers, collaborating from the beginning. These integration questions should guide decisions about what studies to integrate, and what methods to use, and identify incentives for integration to work. Involvement of managers from the beginning provides more effective scientific direction and facilitates the use of the research results in understanding the ecosystem and in the forest management decision process.

PROGRESS TOWARD INTEGRATION

The need for integration has long been recognized since MOFEP was initiated in 1989. During this early phase of the project the concern was raised that MOFEP was concentrated on collecting information on individual ecosystem components, and that in the future, collaborative, integrated research was required (see Brookshire and others 1997, Larsen and others 1997). Current and previous MOFEP strategic plans highlight integration as a priority.

The common research sites, common landscape-scale experimental design, and breadth of research studies in MOFEP provide a good opportunity for addressing multidisciplinary questions through integration. MOFEP study results to date have resulted in 180 publications and more than 240 presentations at national and international meetings. Although many of these products have focused mainly on individual ecosystem components, they have contributed to understanding ecosystem components to forest management and have provided a foundation for integration. The limitation of presenting results from individual studies is that they do not capture the complexity of the ecosystem responses. Synthesis documents that bring together the scientific highlights of MOFEP in a fashion useful to resource managers have been developed, providing some insights on the response of the various ecosystem components. Integration by analyses also has been attempted.

INTEGRATION BY SYNTHESIS

One of the biggest challenges facing managers is to take proper account of relevant research findings in making decisions. A major problem for the potential users of research, be they managers, private landowners, or other researchers, is that they find it difficult or impossible to unearth all the relevant evidence, and decide what it means. Everyone therefore depends on good summaries of research to guide their decisionmaking process. Integration of information by synthesis is helpful in guiding this effort.

Scientists have synthesized MOFEP information from published individual disciplinary studies. An example of a synthesis of MOFEP studies is by Kabrick and others (2004). The purpose of their synthesis was to summarize what has been learned through the first 10 years of MOFEP for vegetation, birds, amphibians and reptiles, and small mammals. Their synthesis indicated that relative to the no-harvest management sites, ground flora richness, total vegetative cover, and woody vines increased and legumes decreased after harvesting. There was little difference in ground flora response between even-aged and uneven-aged treatments. No treatment effects were detected on amphibian and reptile abundances, with one exception. American toad abundance declined on all treatments; the steepest declines were observed on no-harvest treatment sites. Small mammal abundance declined on no-harvest sites yet remained the same on even-aged sites. Mature forest songbird abundance, particularly Ovenbirds, decreased and early successional songbird abundance increased in harvested sites. However, neither nest predation nor nest parasitism increased following treatments. Kabrick and others (2004) concluded that forest management objectives, including regeneration, do not appear to conflict with other management objectives, such as sustaining plant and wildlife communities, because harvesting was not necessarily detrimental to them during the first few years following an initial harvest entry into the forested sites.

Gram and others (1997) compiled a summary of pretreatment analysis of variance results found in 12 MOFEP studies (research on the genetics of woody species, snags and down wood, berry-production plants, acorn production, and surface soils; and seven studies of taxonomic groups at various levels [woody vegetation, ground flora, small mammals, leaf-chewing insects, forest interior birds, herpeto-fauna and *Armillaria*]) to present treatment and block effects. They reported that out of 57 variables assessed, treatment effects were significant for only three: ground flora species richness, density of moth caterpillar (*Dichomeris ligulella*) on white oak (*Quercus alba*), and *Rubus enslenii* abundance. They found significant block effects for 19 of 57 variables. These results showed that sites were variable prior to harvesting in 1996-97 and underscored the importance of having pretreatment information in an experiment of this scale.

Several researchers have discussed their findings in the context of other MOFEP studies. For example, Wallendorf and others (2007) integrated their findings on birds with findings from vegetation responses in the discussion section of their paper. Although they did not do integration by analyses, it was useful to explain how the bird responses might be related to vegetation responses.

Researchers have recently consolidated results that have been found following the first harvest entry into MOFEP sites. They use a matrix format that shows the response of various ecosystem components to the three forest management systems. Matrices covering overstory vegetation, ground flora, birds, reptiles, amphibians, small mammals, dung beetles, and oak insect herbivores have been developed. An example of a matrix is given in Table 1. This matrix of "winners" and "losers" has a zero denoting no treatment effect, "+" denoting a positive effect (increase) and "–" denoting a negative effect (decrease) on the species. This matrix gives busy

Table 1.—Impacts of even-aged forest management (EAM) uneven-aged forest management (UAM), and no-harvest management (NHM) on ground vegetation (<1 m in height) 2 years post-harvest. A zero denotes no treatment effect, + denotes a positive effect, and – denotes a negative effect on the species.

Species/item	EAM	UAM	NHM
Tree seedling density	0	0	0
Species richness	+	+	0
Ground cover	+	+	0
Annuals/biennials	+	+	+
Forbs	0	0	0
Graminoids	+	+	0
Legumes	-	-	0
Woody vines	+	+	0
Shrubs	0	0	0
Nonnative species	0	0	0

managers a reference that is brief and to the point and has allowed the researchers to interpret their data for the reader. The matrix gives managers something to work from in the near term and encourages them to dig deeper when they have the time and interest.

These syntheses define current scientific understanding and integrate MOFEP findings in a format that managers and administrators can use without reading the voluminous reports of individual studies. However, the integration by synthesis has been useful in summarizing findings in an easy to understand format but provides little insight into the interactions within and among the ecosystem components. They assume that immediate effects of forest management on the different ecosystem components are additive (i.e., the total is equal to the sum of the parts) and hence ignore interactions among components. On the other hand, integration by analysis allows correlations to be inferred and thus provides a more holistic understanding where the whole is more than summing up the results from the different components.

INTEGRATION BY ANALYSIS

The first integration by analysis study was by Gram and others (1997), who identified potential interactions among individual species by performing correlation analyses (using product moment correlations) on density and relative abundance of 24 species from the seven different taxonomic groups of plants and animals. They found 25 potential interactions and 80 percent of them were between species from different taxonomic groups. For example, shortleaf pine (*Pinus echinata*) and wood thrush (*Hylocichla mustelina*) densities were positively correlated (r = 0.84), and sassafras (*Sassafras albidum*) relative abundance was negatively correlated with spotted salamander (*Ambystoma maculatum*) (r = –0.85). They concluded that the predominance of intertaxa correlations confirmed the importance of integrating data among taxa because it is likely that some of these relationships influence widespread ecosystem processes. They also correlated the taxonomic groups across the year the land was acquired by MDC to explore potential effects of land-use history on taxa abundance patterns. They found correlations between six groups of taxa, including high positive correlations between woody vegetation and ground flora (r = 0.95), and high negative correlation between woody vegetation density and sassafras inbreeding coefficient (r = –0.99). These results suggested that patterns of species succession in plant communities may be directly related to land-use history.

The second study was by Gram and Sork (1999), who evaluated 1) the relationship between genetic diversity indices and density (seedlings, small trees, and large trees); and 2) the relationship between genotypic composition and density measures of three species (*Q. alba*, *Carya tomentosa*, and *Sassafras albidum*) using canonical correlation analysis. Canonical correlation analysis is a generalized multiple regression between two groups of variables. In their case, they modeled genetic diversity as the dependent variable group and population density as the independent variable group, and genotypic composition (i.e., the multilocus genotype of each individual per population) as the dependent variable group and population density as the independent variable group. They found that population density was not correlated with genetic diversity in large populations of plant species, but density was associated with genotypic composition of populations. These results indicated that populations with small densities had different genotypes than those with large densities, suggesting that preserving populations with different densities increases the chance of maintaining a variety of genotypes.

The third study was by Gram and Sork (2001), who evaluated 1) the correlation between forest structure variables (basal area, large tree density, medium tree density, small pine density) and individual genotypes for each species using composite variables generated from a canonical correlation analysis; and 2) the relationship between environmental characteristics (soil and aspect) and the distribution of genotypes for three common woody species (*Quercus alba*, *Carya tomentosa*, and *Sassafras albidum*). They tested whether genotypes differed among four soil-type/aspect classes with multivariate analysis of variance (MANOVA), treating individual genotypes as dependent variables. They found significant correlations between mean population genotypic vector and the forest structure vector in *Quercus* ($r = 0.67$), *Carya* ($r = 0.85$), and *Sassafras* ($r = 0.57$). They found that genotypic composition was associated with environmental variation but did not find any differences in genotypes among soil-type/aspect classes in any of the three species.

The fourth study used meta-analyses to determine effects of forest management on animal community diversity after the first entry harvest (Gram and others 2001). Meta-analysis is a statistical approach that facilitates integration of results across a set of studies on multiple species groups. A meta-analysis reports findings in terms of effective sizes, which in the case of this study, were estimated as standardized mean difference for each ecological group. Data used for the analysis consisted of densities or relative abundance for amphibians and reptiles, birds, small mammals, and leaf-chewing insects. They found that following first entry harvest, 1) animal communities showed an overall short-term change in response to even-aged and uneven-aged management; and 2) individual species groups responded differentially to management treatments (Table 2). For example, significant treatment effects for early successional birds were detected in 1997 and 1998, and for toads and forest interior birds in 1998. This analysis provided insight into how this first entry harvest affected multiple species groups.

The fifth study used Bayesian spatial modeling to integrate data (Sun and others 2008, Zang 2008). Sun and others (2008) mapped site index using covariates in the model. The covariates were aspect class, land type association, and soil depth. Results showed that aspect class and soil depth were both significant while land type association was less significant. Total vegetation coverage data were also analyzed with aspect class, land type association, and soil depth as covariates (Sun and others 2008). Results showed that the soil depth covariate was an important factor while the aspect class was less important when modeling the total vegetation coverage. Zang (2008) extended the work by Sun and others (2008) by spatially modeling vegetation coverage by an individual species where excess zeros exist. They developed the new model 'Zero-inflated Bayesian

Table 2.—ANOVA probabilities for treatment effects for ecological groups of species in 1997 (1 year after harvest) and 1998 (2 years after harvest) (Gram and others 2001).

Ecological Group	1997	1998
Ambystoma salamanders	0.603	0.268
Plethodon salamanders	0.917	0.620
Toads	0.086	0.018
Skinks	0.368	0.434
Small snakes	0.786	0.642
Peromyscus species	-	0.106
Forest interior birds	0.480	0.004
Edge/early successional birds	0.007	0.003
Free-feeding caterpillars, black oak	0.673	0.894
Leaf-rolling caterpillars, black oak	0.654	0.577
Free-feeding caterpillars, white oak	1.000	0.776
Leaf-rolling caterpillars, white oak	0.889	0.924

Spatial model' and illustrated its use on *Desmodium nudiflora* and *Cornus florida* (both with zero vegetation cover percent in many plots) to model spatial relationships among the coverage proportions of the two species collected at selected locations and predict the coverage on an unmeasured location.

Recently, researchers at the University of Missouri-St. Louis have been working on the interactions between avian and insect herbivore communities within MOFEP using regression analysis. The study is based on the idea that birds and herbivorous insects interact: birds eat herbivorous insects, and potentially control the population levels of those insects, at least in non-outbreak years. Some of the preliminary results indicate that 1) birds drive down insect populations locally; 2) birds affect insect community structure; and 3) plant species affect bird-insect interactions.

TOOLS FOR INTEGRATION – CONCEPTUAL MODELS

As part of the MOFEP 2006-11 strategic plan, the MOFEP Steering Committee developed five conceptual models: an overarching model, a physical environment submodel (Fig. 1), a human impact submodel, a fauna submodel, and a flora submodel. The overarching model defines the relationships of the primary ecosystem components while each submodel captures the feedbacks among the components in the submodel, and forest structure and composition. The models developed were a consensus of opinion among MOFEP partners on key ecosystem components and their linkages, and help in understanding ecosystem complexity. The conceptual models have been used by the MOFEP Steering Committee to identify individual studies implemented in MOFEP and the research gaps that have been determined. For example, air, water, and wildfire ecosystem components in the physical environment submodel have not been addressed. In the future, the models will be used as a basis for conducting further integration studies because identification of linkages among ecosystem components is a key to designing and conducting syntheses and analyses that provide managers with usable information.

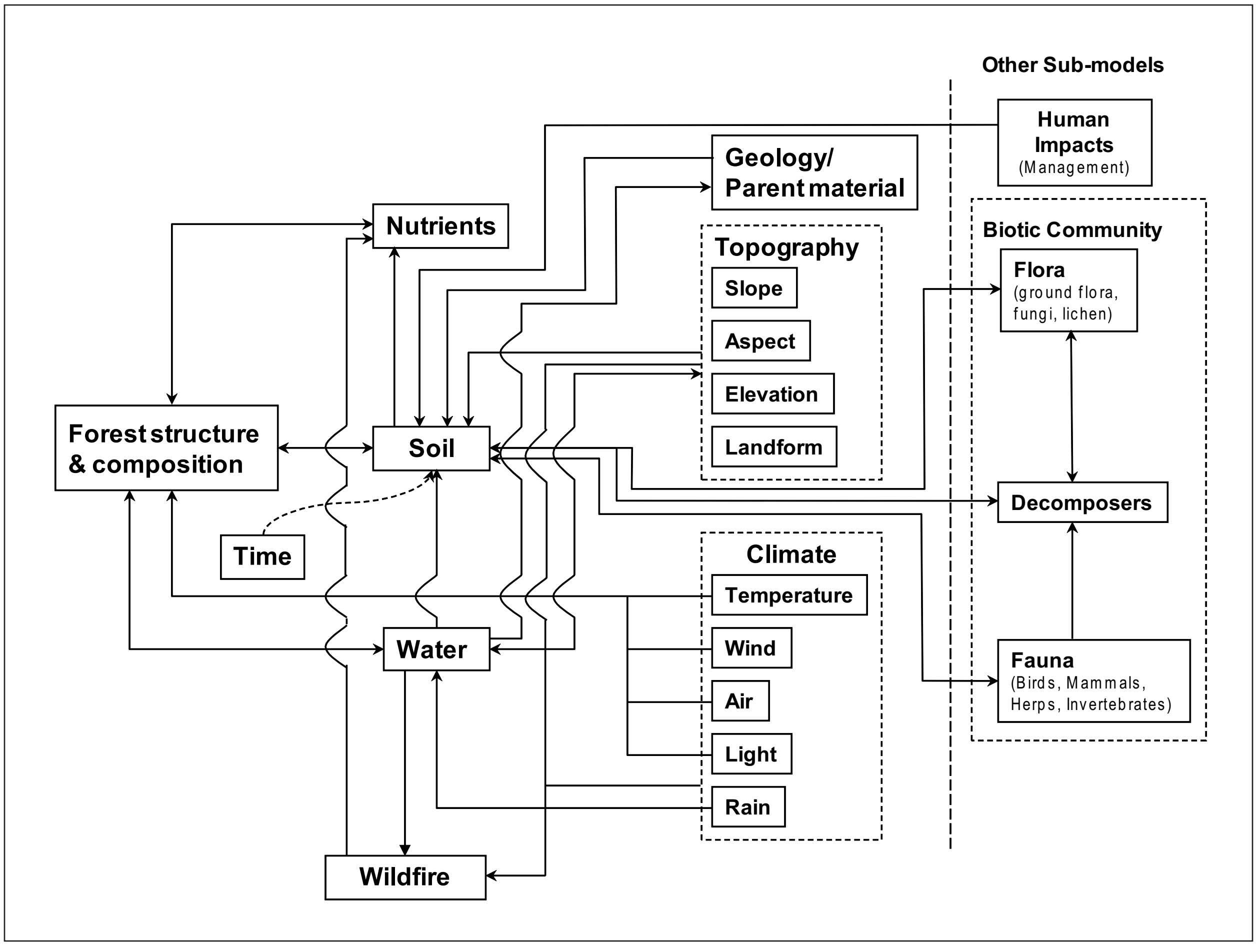

Figure 1.—An example of one of the five MOFEP conceptual models. This conceptual submodel for the MOFEP physical environment shows key linkages among physical environment components, forest structure and composition, and other submodels. Integration is central to the effort to learn more about the connections of these important ecosystem components.

INTEGRATION CHALLENGES

Recent attempts at integration have provided substantial insight into this challenging task. Furthermore, various meetings of the MOFEP researchers and the MOFEP Steering Committee members have highlighted some of the challenges. For integration to grow, many issues must be resolved. These issues can be categorized into five areas: definition, planning, data management, scale, and personnel.

DEFINITION OF INTEGRATION

As pointed out earlier in this paper, to advance integration we must be sure that the term is well defined, and hence, well understood. We have attempted to define the term in this paper. It is important that all stakeholders discuss this definition and that current and future researchers and managers agree upon and communicate common definition. We do not necessarily believe that the definition reached through this consensus will be static throughout the life of MOFEP, but it needs to be explicitly stated and referenced by all involved.

PLANNING

Planning for integration is one of the most important challenges in MOFEP. Ideally, any integration or data collection should not be done until the planning stage has been well articulated. Individual study designs rely upon knowing how the data will be analyzed and used in integration analyses. Armed with this knowledge, researchers can design the studies of individual ecosystem components to facilitate integration analyses. In reality, integration has been somewhat ad hoc with individual researchers interested in integration taking the lead. Because many of MOFEP's studies were not designed knowing what integration analyses were to be conducted, integrating data among studies has been analytically difficult. Integration done in the absence of planning also does not guarantee that priority integration questions will be addressed.

Planning for integration starts with clear and precise questions/hypotheses to justify and drive integration. These questions are essential to give context and focus to integration. According to Pickett and others (2007), integration requires that we know what we want to integrate and how to achieve it. Integration is a means to an end, requiring agreement about the goal before deciding on how to get there. Attempting to implement integration without clear questions is likely to produce poor decisions and questionable ecosystem management results. Formulating the integration questions will help select a smaller number of ecosystem components or elements whose measurements will effectively inform management. Developing these integration questions ensures that limits on scientists' time, expertise, and funding are accommodated. It also ensures that actions (methods, expertise, funding) to address these questions can be developed or identified. Limited resources and prevalence of many interactions at the ecosystem level mean that not everything can be integrated. Thus, planning will ensure that limited resources are spent on addressing the critical management questions.

Because integration questions should be driven by stakeholder interests, time spent initially on stakeholder analysis, and identifying stakeholder concerns, will avoid subsequent development of partial, inadequate integration. It is recommended that the MOFEP Steering Committee should continue to take a lead role in facilitating discussions to develop the integration questions.

DATA MANAGEMENT

Data archiving and metadata are integral components of integration. Before integration and synthesis of MOFEP studies can begin in earnest, the data need to be well defined, error-free, and readily available. MOFEP has implemented strong data management systems and policies that define clear roles of researchers in terms of data and metadata submission, and there are clear policies in terms of data access and data sharing. MOFEP data are stored in a computerized information system, making it valuable not only to the research staff but to the broader scientific community. The MOFEP data archive is a Web-based system, which allows primary investigators to enter information about their projects and publications, to upload datasets to the archive, and to view metadata and data from other projects. The MOFEP Steering Committee developed guidelines for data access. The guidelines specify who should provide the data, when the data will be available to the public, and conditions and mechanisms for access. One of the defining characteristics of the policy is MDC's commitment to open access to MOFEP data. Open access is viewed as essential for maintaining and improving knowledge of ecosystem response to management activities in Missouri and beyond. It is hoped that these guidelines will facilitate the appropriate use of MOFEP data by the bona fide scientific community, including outside scientists interested in cross-site analyses and integration.

The challenge in MOFEP is timely submission of data and quality control of the data. A future challenge will be to evaluate data collection plans with a view to revise them so that they include appropriate data to answer integration questions as they are developed.

SCALE

MOFEP data are collected at different spatial scales: leaf (e.g., oak herbivores), tree (e.g., stump sprouting), small plot (e.g., ground flora), large plot (e.g., overstory vegetation), and compartment (e.g., birds); and at different temporal scales (e.g., four times per year, annually, every 5 years). Integrating such data presents challenges. In addition, the various studies have different sampling methods (different plot locations, different plot sizes, different layouts, etc), making integration even more challenging. To make integration work, effective analytical methods must be developed to accommodate the different range of scales for the various ecosystem components.

RESOURCES

One of the challenges limiting integration is probably the physical separation of scientists – some scientists are in Oklahoma and Ohio and those in Missouri represent different agencies and are scattered throughout the state. This is not to say that scientists widely separated cannot work together, but it can be a constraint to building good working relationships needed for integration to work well.

With MOFEP, we found the greatest progress toward achieving integration occurred when a scientist was hired to work full time on integration. A major challenge was finding a qualified and experienced person in integrated research and ecosystem modeling. Few scientists have training or experience using the appropriate statistical tools needed for the analysis of complex datasets or the expertise to synthesize disparate datasets spanning multiple disciplines without assistance. Integrative research requires good administrative support by the research institution, a clear mandate guided by integration questions, and good working relationships with the principal investigators who developed data to be integrated.

We believe that developing incentives may accelerate the integration efforts. An example of such incentives is funding (e.g., multidisciplinary study proposals that specifically include integration will receive funding priority).

CONCLUSION

MOFEP integration has been encouraged since the project started. In fact, one of the bases for MOFEP is integration; therefore, MOFEP and integration are synonymous. Integration has been occurring in MOFEP, but more could be done. Integration has been constrained by a lack of common understanding of what integration is, and lack of clear plans, including formulation of the integration questions. The breadth of studies, wealth of existing data, integration experience gained from past efforts, existing integration tools, development of more sophisticated integration tools, continued discussions on how to improve integration, and commitment to continue this long-term study are sufficient to advance MOFEP for the benefit of the ecological community.

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