Missouri Ozark Forest Ecosystem Project: The Experiment

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Abstract.—The Missouri Ozark Forest Ecosystem Project (MOFEP) is a unique experiment to learn about the impacts of management practices on a forest system. Three forest management practices (uneven-aged management, even-aged management, and no-harvest management) as practiced by the Missouri Department of Conservation were randomly assigned to nine forest management sites using a randomized complete block design. Unique features of the MOFEP experimental design include collection of pre-treatment information, use of replicate forest management units, and the long-term nature of the project. In the case of MOFEP, pre-treatment data were collected up to 5 years before the harvest treatments were applied in 1996-1997. The design of MOFEP also allows for three complete rotations of harvest treatments with each site. Since the periods between the application of even-aged and uneven-aged harvest practices will be 10 to 15 years and the rotation length will be about 100 years, we expect the life of MOFEP to be at least 300 years. Throughout this project, results will provide information valuable to understanding and designing forest management practices that will benefit forest ecosystem health. Through MOFEP's example, lessons can be learned about the application of large-scale (spatially and temporally) experiments in natural resources management. The MOFEP experience has demonstrated that learning about the impacts of management on natural ecosystems can be accomplished on a scale relevant to managers and researchers.

Forest management, as well as most other natural resources management, has moved into an era in which decisions must be based on sound science that correctly predicts the outcome of the chosen practice. In Missouri, the public demands science-based forest management decisions (Missouri Department of Conservation 1996, Palmer 1996). Conducting research for making sound predictions requires going beyond developing hypotheses. Research that tests hypotheses and theory is required before predictions can be made with any certainty.

During the mid-1980s, the impact of forest management on neotropical migrant songbirds caught the attention of ornithologists and the public alike. Monitoring of bird communities in forest systems led to hypotheses of how these communities might be affected by forest management (Annard and Thompson 1997; Robbins *et al.* 1989; Robinson *et al.* 1995; Thompson *et al.* 1992, 1993). These hypotheses, however, had not been rigorously tested to develop information useful in predicting implications for forest management decisions. Short-term data from these studies provided the foundation for sound hypotheses and helped establish theories that decision makers could consider. However, these hypotheses and theories about the effects of forest management on the bird communities and the entire forest ecosystem needed testing.

Romesburg (1981) called for natural resources management and research to go beyond hypothesis development to hypothesis testing. In a decision process, if only untested hypotheses are used, then "educated guesses" as to the viability of each hypothesis are required. The decision maker must rely upon his or her own experiences and perceptions in predicting the outcome of management alternatives. The uncertainty in hypotheses and predictions is not

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easily evaluated in the informal atmosphere that often accompanies the natural resource decision making process (Walters 1986). Even though in most cases the decision maker may understand and "mentally" evaluate the impacts of a management decision, the information gained is not often or easily transmitted to the next generation of decision makers. In other words, lessons learned through experience are often lost. To "learn" while managing requires a more formal framework for the decision process. Walters (1993) advocated the use of large-scale field experiments in impact assessment and management. Romesburg (1981) advocated the use of hypothetico-deduction when testing hypotheses. By combining the hypothetico-deductive process with the management by experiment idea, experiments are designed to determine cause-and-effect relationships among management alternatives. Through this paradigm and the desire to confront forest management decisions based on data, the Missouri Ozark Forest Ecosystem Project (MOFEP) was designed and implemented.

Designing MOFEP was a difficult task that required much thought and cooperation over several years (Kurzejeski *et al.* 1993), but there was a tremendous desire to implement a project that would provide an opportunity to learn about impacts of different forest management practices at a landscape scale typically used by managers in the Missouri Ozark forests. The development of this unique project in the late 1980s required a herculean effort by many individuals (Brookshire *et al.* 1997, Kurzejeski *et al.* 1993).

Objectives of this paper are: (1) to provide a review of the design of MOFEP, (2) to supply background information on the forest management treatments, and (3) to critique MOFEP so that others might learn from our experiences when designing similar projects in other ecosystems. Our goal is to provide information about things that we have done right and those that we have done wrong.

THE MOFEP DESIGN

MOFEP was initiated in 1989 to investigate forest management effects on the forest and wildlife community of the Missouri Ozarks (Brookshire *et al.* 1997). In designing MOFEP, we used experimental design techniques emphasizing the manipulative or hypothetico-deductive approach for hypothesis testing (Sheriff and He 1997). The manipulative experimental approach employed in MOFEP allows for cause-and-effect relationships to be inferred (Eberhardt and Thomas 1991, Green 1979, James and McCulloch 1985, Romesburg 1981, White and Garrott 1990).

To be successful, an experiment must have five major components (Hurlbert 1984): (1) the hypothesis, (2) experimental design, (3) experiment execution, (4) statistical analysis, and (5) interpretation of results. If one of these elements is missing or completed poorly, doubt and suspicion can cloud the usefulness of the results in the decision process and compromise the value of the experiment.

The Hypothesis of MOFEP

MOFEP's null hypothesis is that no effects on ecosystem components, such as vegetative and animal communities, will be found due to the forest management practices used (Sheriff and He 1997). This hypothesis is a testable statistical hypothesis. It is reasonable and desirable to determine if forest management practices affect different components of the forest ecosystem. This null hypothesis, however, is also a nonsensical hypothesis, because we know that it is false from the beginning (Johnson 1999). By merely harvesting a single tree within a forested area, we affect the forest in some way. The challenge is to measure the impact and magnitude of this manipulation. The question also needs to be asked: does this manipulation create a significant biological difference even if a statistical difference can be found (Steidl *et al.* 1997)?

To defend the stated hypothesis of MOFEP, it is important to understand that it is testable and allows us the opportunity to learn about the uncertainties associated with forest management. By testing this hypothesis, we can learn about the magnitude of differences, the temporal aspect of effects, the ways in which different forest management practices diverge and converge through time, and their similarities and differences. The time series of data derived from each experimental unit is important in our understanding of how the null hypothesis is shown to be false during the statistical analysis phase of the experiment (more on this topic in the experimental design section).

The Experimental Design of MOFEP

The experimental unit chosen for MOFEP is the site (Brookshire *et al.* 1997). Each site is a large forested area typically managed as a unique administrative unit. Nine sites were defined for use in MOFEP in Carter, Reynolds, and Shannon Counties in the southeast Missouri Ozarks. This part of Missouri is approximately 84 percent forested. The area has not been glaciated and most soils have been exposed for more than 250 million years. Physical site characteristics are presented in detail by Meinert *et al.* (1997) and Kabrick *et al.* (2000). Selected sites had to be: (1) at least 600 acres in size; (2) in contiguous tracts with minimal edge; (3) largely free from manipulation for at least 40 years and preferably longer (i.e., less than 5% of area disturbed); (4) owned by the Missouri Department of Conservation (MDC); (5) located in the southeast Missouri Ozarks; and (6) in close proximity to each other. Sites were selected following a search of MDC inventory records, discussions with local site managers, and numerous aerial and field evaluations (Kurzejeski *et al.* 1993). Additional description of the study area is provided by Brookshire *et al.* (1997), Brookshire and Hauser (1993), Brookshire and Shifley (1997), and Shifley and Brookshire (2000) (fig. 1). MOFEP experimental sites are analogous to forest compartments and each includes between 41 and 70 forest stands.

Three forest management practices were defined as treatments (Brookshire *et al.* 1997): uneven-aged management, even-aged management, and no-harvest management. The nine sites were visually inspected to determine if like sites could be blocked to aid in the efficiency of the experimental design. Through these observations, three blocks containing three sites each were made. A randomized complete block design (Steel and Torrie 1980:196-197) was used to assign treatments to sites within each block (Sheriff and He 1997).

To strengthen the design and increase the "learning power" from MOFEP, data were collected in the 5 years before treatments were begun. These pre-treatment data are critical to understanding the impacts of the three forest management practices (Sheriff and He 1997). For example, if information from MOFEP resembled that shown in figure 2A, then we would conclude that forest management practice 2 had an impact. If data resembled those shown in figure 2B, then we would conclude that forest management did not have an impact. If only post-treatment data were available, figure 2B would appear to indicate practice 2 had an impact. If results resembled those shown in figure 2C, then we might conclude that there was a confounding of effects due to the treatments or there was some broader ecological impact occurring at the time treatments were applied. Without the pre-treatment data, we might not even be aware of the phenomenon demonstrated in figure 2C.

The Execution of MOFEP

Treatments

The three forest management treatments compared in the MOFEP experiment are even-aged management (EAM), uneven-aged management (UAM), and no-harvest management (NHM) (fig. 3). These treatments represent the range of silviculture practices applied on private and public lands in Missouri. Treatments are briefly described below; additional detail is available in Brookshire and Hauser (1993) and Brookshire *et al.* (1997).

Even-aged Management

Even-aged management followed MDC Forest Land Management Guidelines (1986), with a cutting rotation of 100 years. Under this management, approximately 10 percent of each site (i.e., each compartment) is left as old growth and reserved from harvest in perpetuity. In the remainder of the site, the desirable tree size class distribution is 10 percent seedlings, 20 percent small trees (2.5 to 5.5 in. or 6 to 14 cm diameter at breast height (d.b.h.)), 30 percent poles (5.6 to 11.5 in. or 14 to 29 cm d.b.h.) and 40 percent sawtimber (>11.5 in. or 29 cm d.b.h.). To achieve this size distribution, regulated harvests of 10-12 percent of the area per entry are done on a 10- to 15-year re-entry period. Harvest prescriptions follow Roach and Gingrich (1968). For MOFEP's first entry into even-aged managed sites, clearcutting was used to regenerate stands scheduled for harvesting. With clearcutting, nearly all trees are cut down except for some snags or den trees left to provide wildlife shelter and for some shortleaf pine (*Pinus echinata* Mill.) left to provide seed for pine regeneration. Non-merchantable trees that were not harvested are cut down during slashing operations following commercial harvesting.

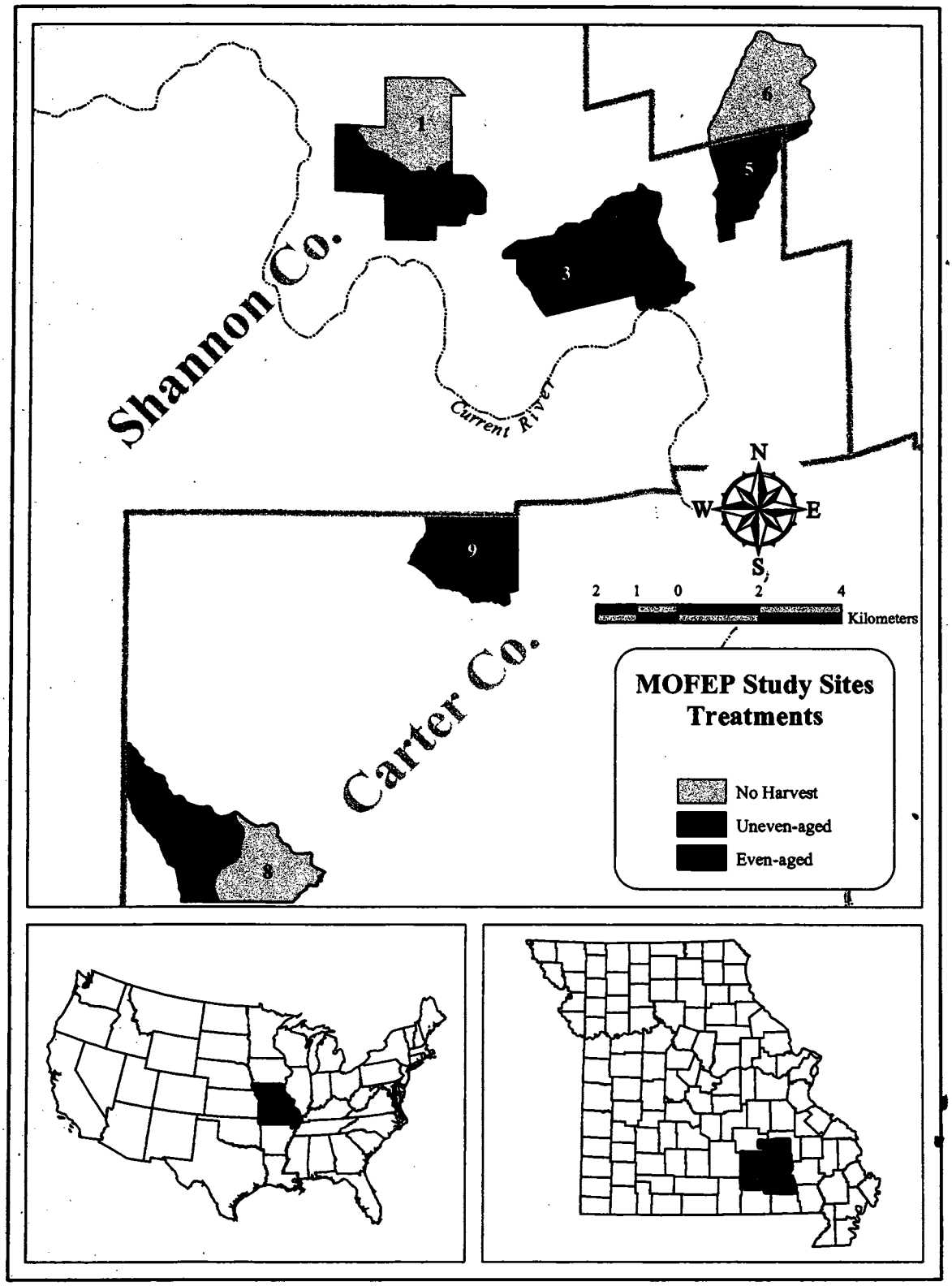


Figure 1.—*Location of the nine MOFEP experimental sites (compartments) and their assigned treatments. See figure 3 for additional detail about each site.*

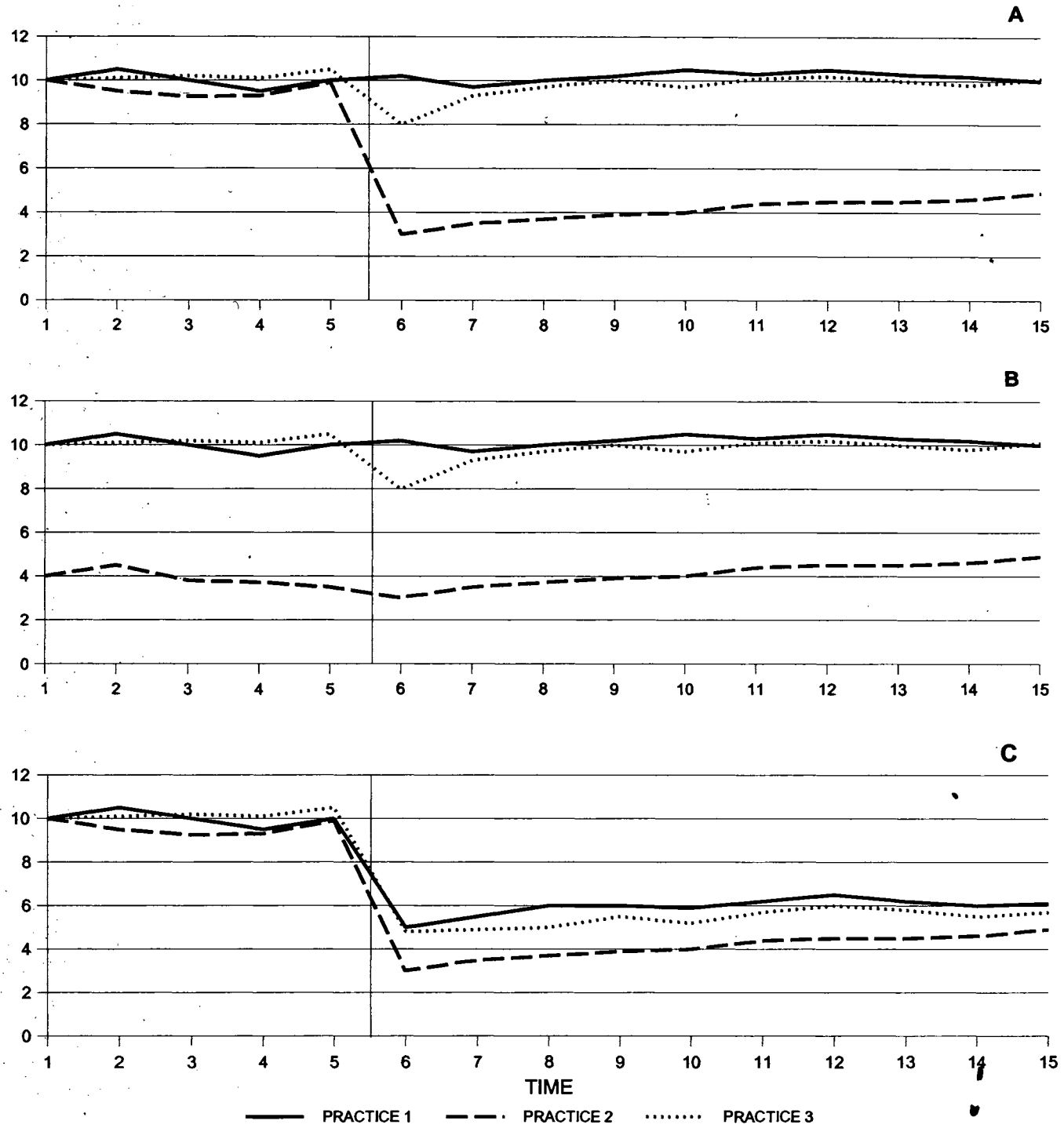


Figure 2.—*Illustration of results from three experimental studies showing importance of pre-treatment data. Illustration A shows a treatment effect for practice 2, whereas illustration B has no treatment effect. Illustration C shows a possible confounding of treatments or a broad ecological effect at the time of treatment. Vertical line between period 5 and 6 shows when treatment was applied.*

Data Collection Location Legend

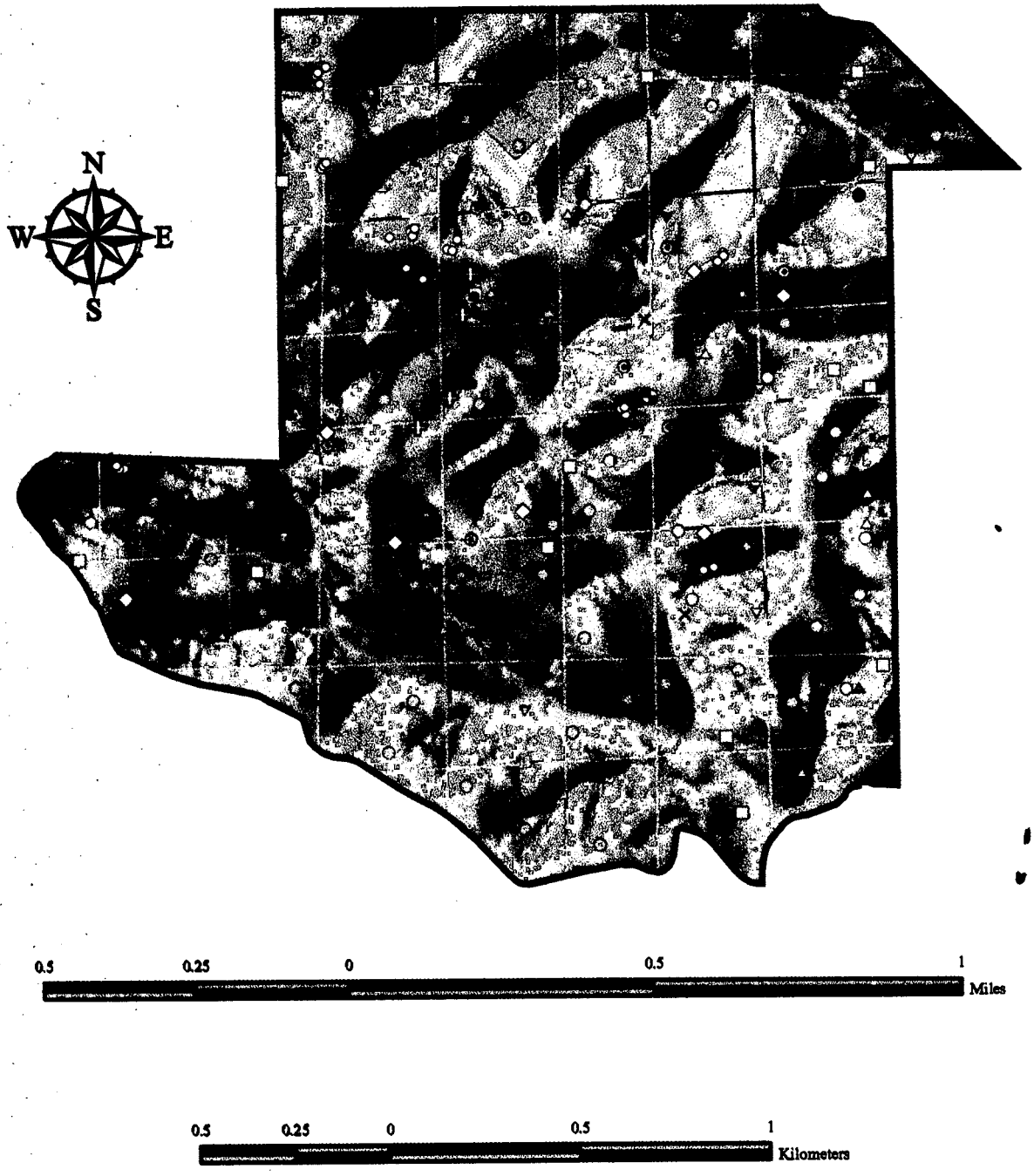
- *Permanent Weather Station* *(Chen et al., 1997[1])*
- *Sampled Soil Profile* *(Meinert, 2001[2])*
- *Soil Nutrient Sample* *(Spratt)*
- *Soil Nutrient Sample, Watershed Study* *(Spratt)*
- *Litter Invertebrate Sample* *(Weaver and Heyman, 1997[1])*
- *Canopy Invertebrate Sample* *(Marquis et al.)*
- *Genetic Sample* *(Apsit et al.; Guyette and Kabrick)*
- *Hard Mast Sample Plot* *(Vangilder, 1997[1])*
- *Vegetation Plot With Armillaria Sampling*
  (Bruhn et al.; Grabner and Zenner; Kabrick et al.; Dey and Jensen; Jensen and Kabrick; Guyette and Kabrick)
- *Vegetation Plot*
  (Dey and Jensen; Grabner and Zenner; Jensen and Kabrick; Kabrick et al.; Guyette and Kabrick)
- *Herpetofaunal Array* *(Renken and Fantz; Guyette and Kabrick)*
- *Bird Transect* *(Clawson et al.; Guyette and Kabrick)*
- *Small Mammal Sample Grid* *(Fantz and Renken)*
- *Uneven-aged Management Stands* *(Sheriff)*
- *Even-aged Management - Clear Cut Stands* *(Sheriff)*
- *Even-aged Management - Intermediate Cut Stands* *(Sheriff)*

[1] See Brookshire, Brian L.; Shifley, Stephen R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project Symposium: An Experimental Approach to Landscape Research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station

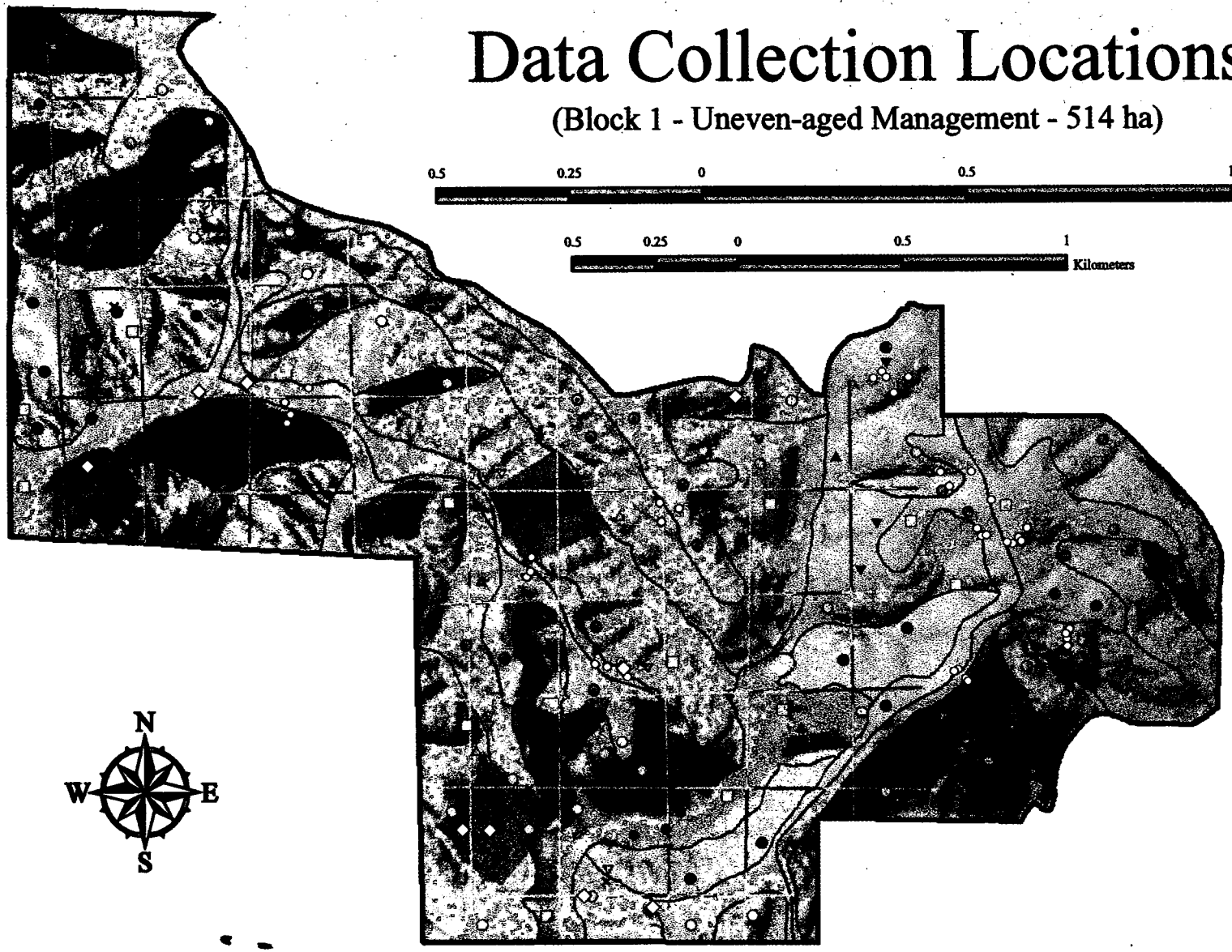
[2] Meinert, D.M. 2001. Soils-Geo-Landform Relationships and the Missouri Ozark Forest Ecosystem Project. Missouri Department of Conservation Publication.

Figure 3.—*The nine MOFEP sites (nine maps plus a legend) showing the areas treated by clearcutting or intermediate thinning (even-aged treatment) and by individual-tree selection or group selection (uneven-aged treatment). Sampling locations for all the associated MOFEP studies are also shown. The legend indicates sources of more information about methods and results for the various studies. When the legend lists an author without a publication date, the reference is to another paper included in this proceedings. See figure 1 for the general location of each site, and see table 1 for a summary of harvested volumes and areas.*

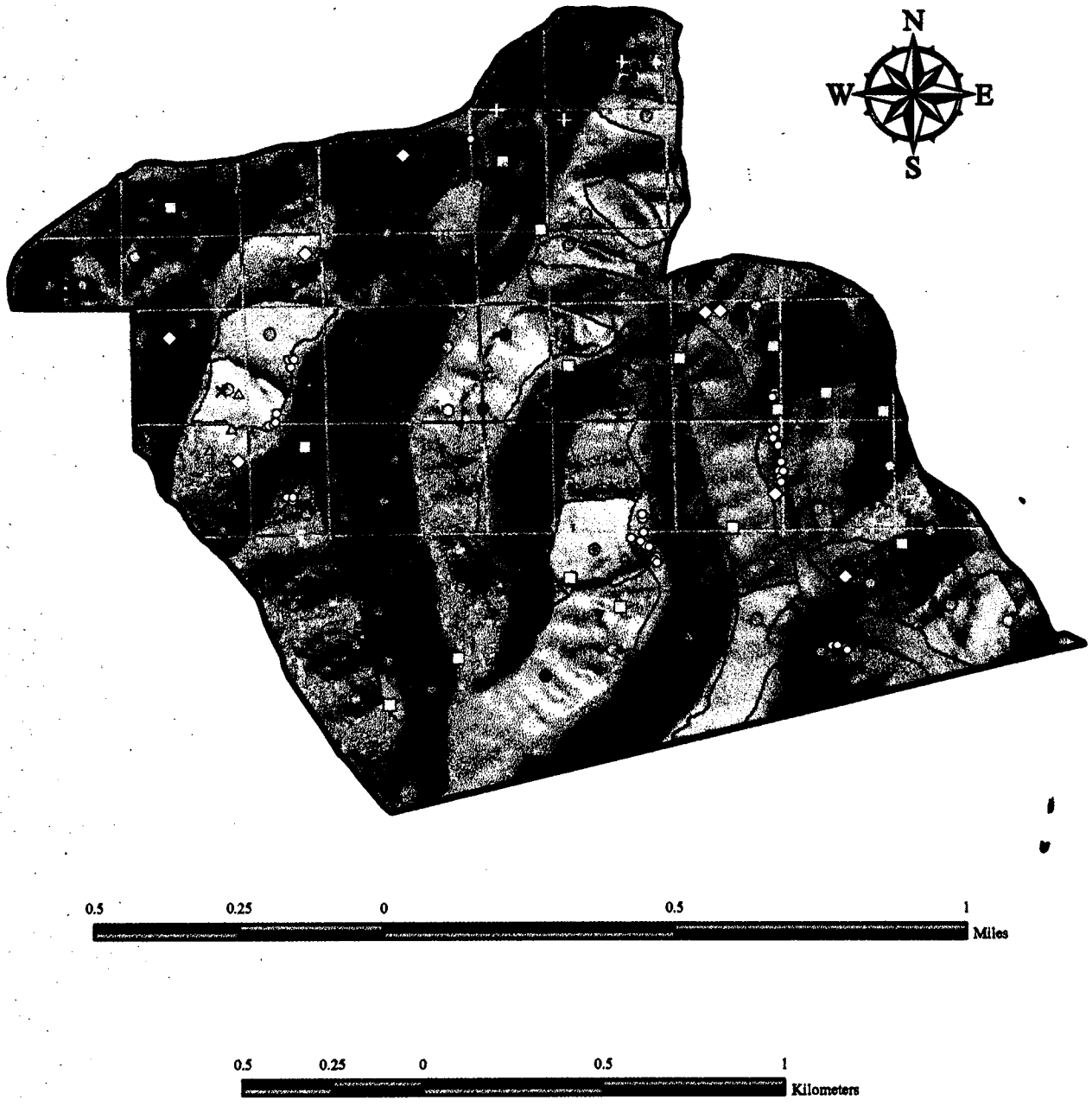
Site 1
Data Collection Locations
(Block 1 - No Harvest Management - 389 ha)



Site 2
Data Collection Locations
(Block 1 - Uneven-aged Management - 514 ha)

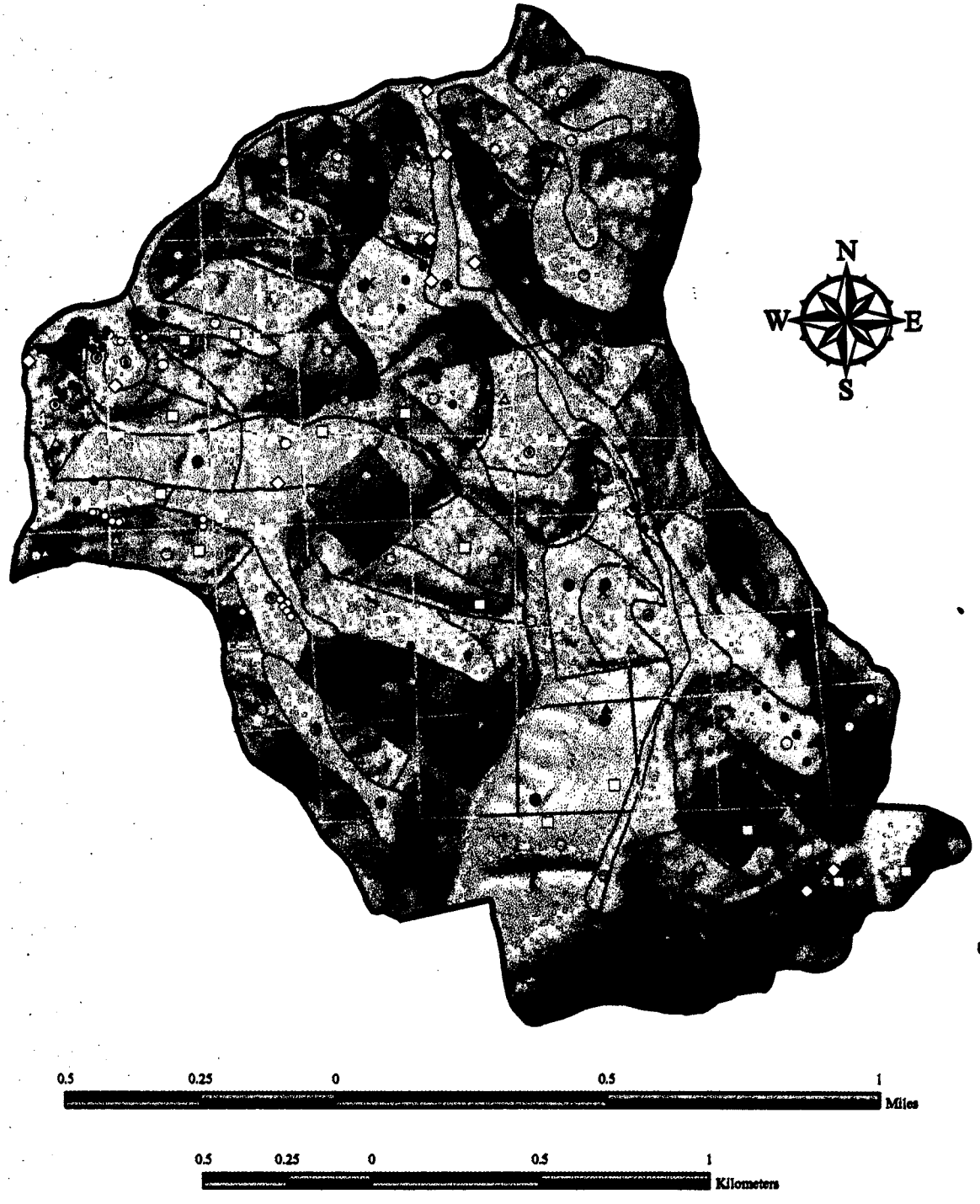


Site 3
Data Collection Locations
(Block 1 - Even-aged Management - 360 ha)



Site 4
Data Collection Locations

(Block 2 - Uneven-aged Management - 479 ha)

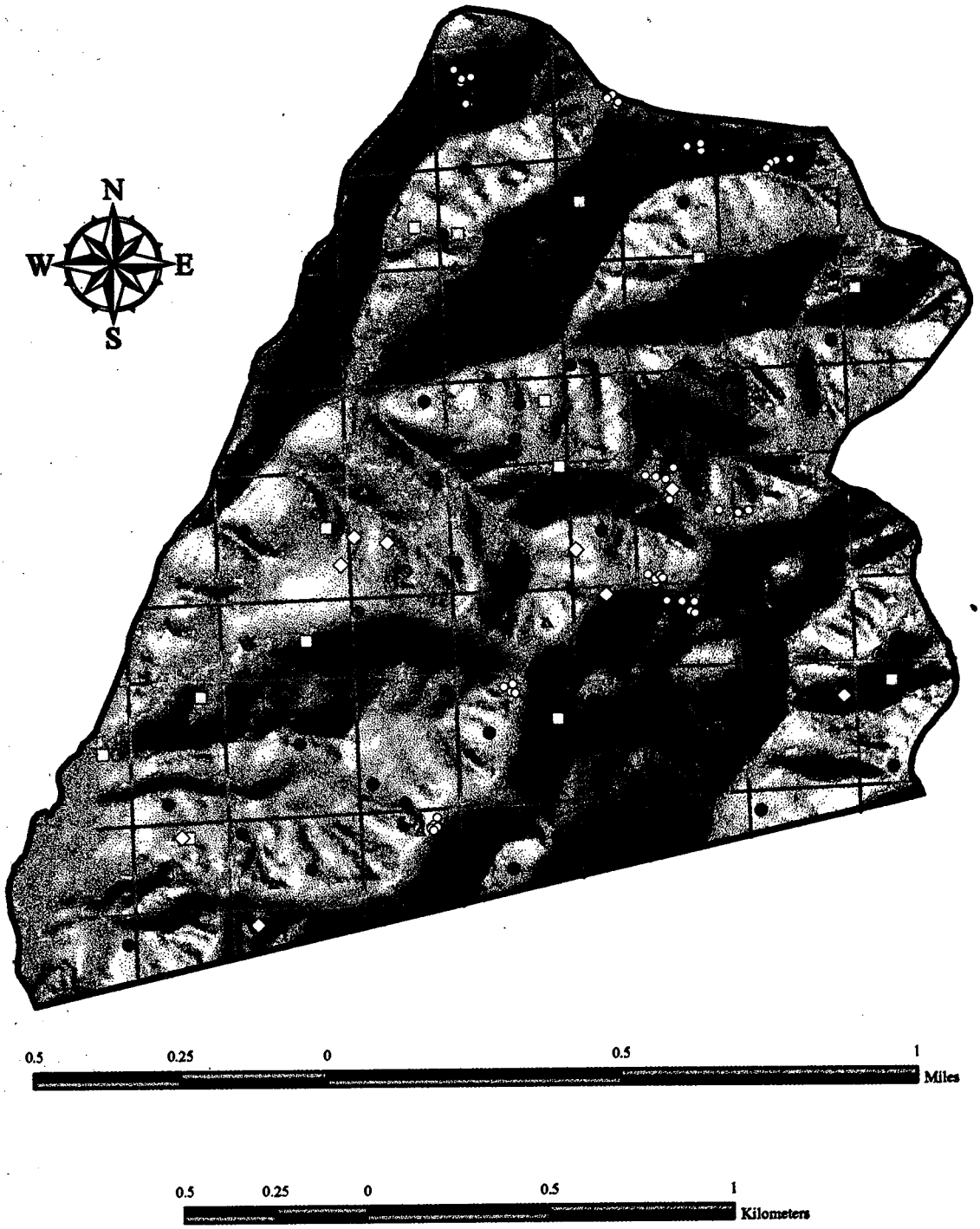


Site 5
Data Collection Locations

(Block 2 - Even-aged Management - 312 ha)

Site 6
Data Collection Locations

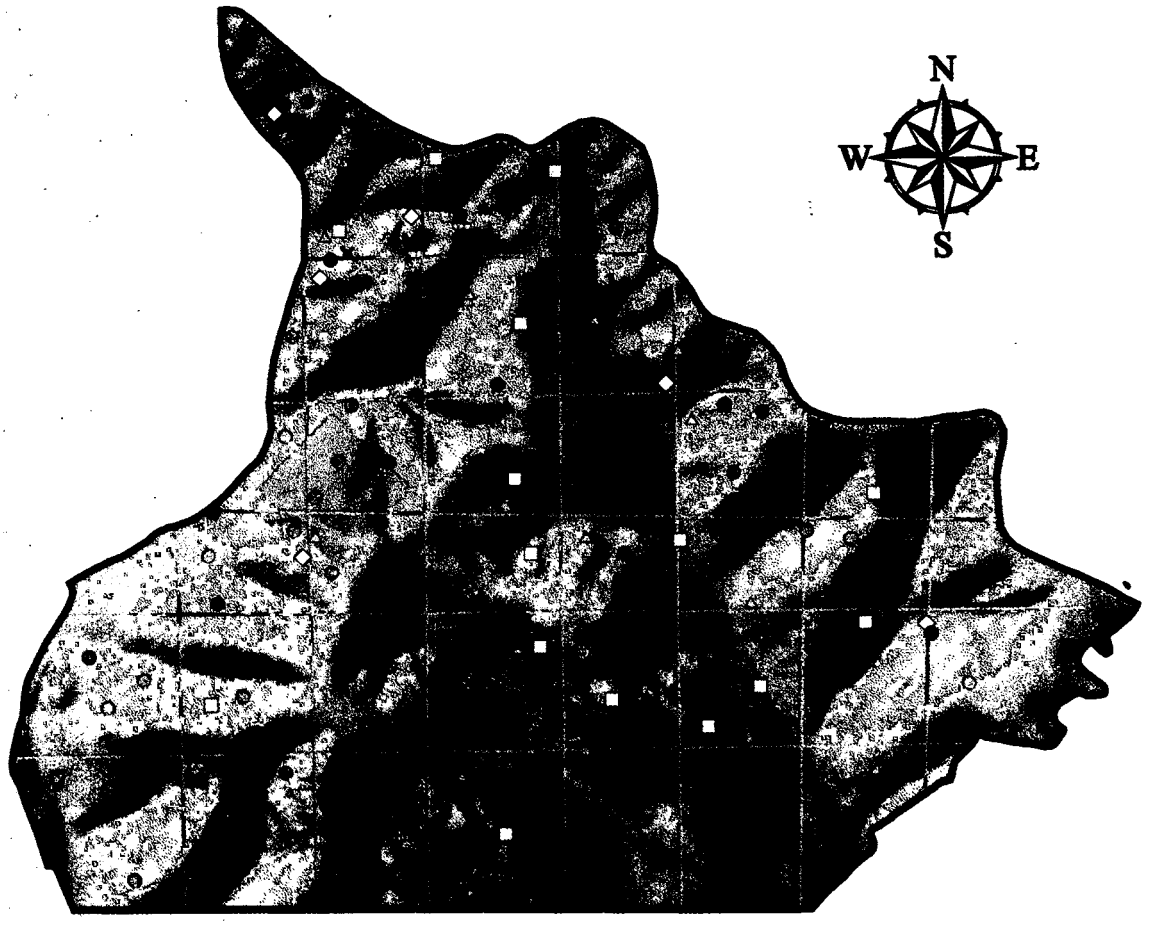
(Block 2 - No Harvest Management - 440 ha)



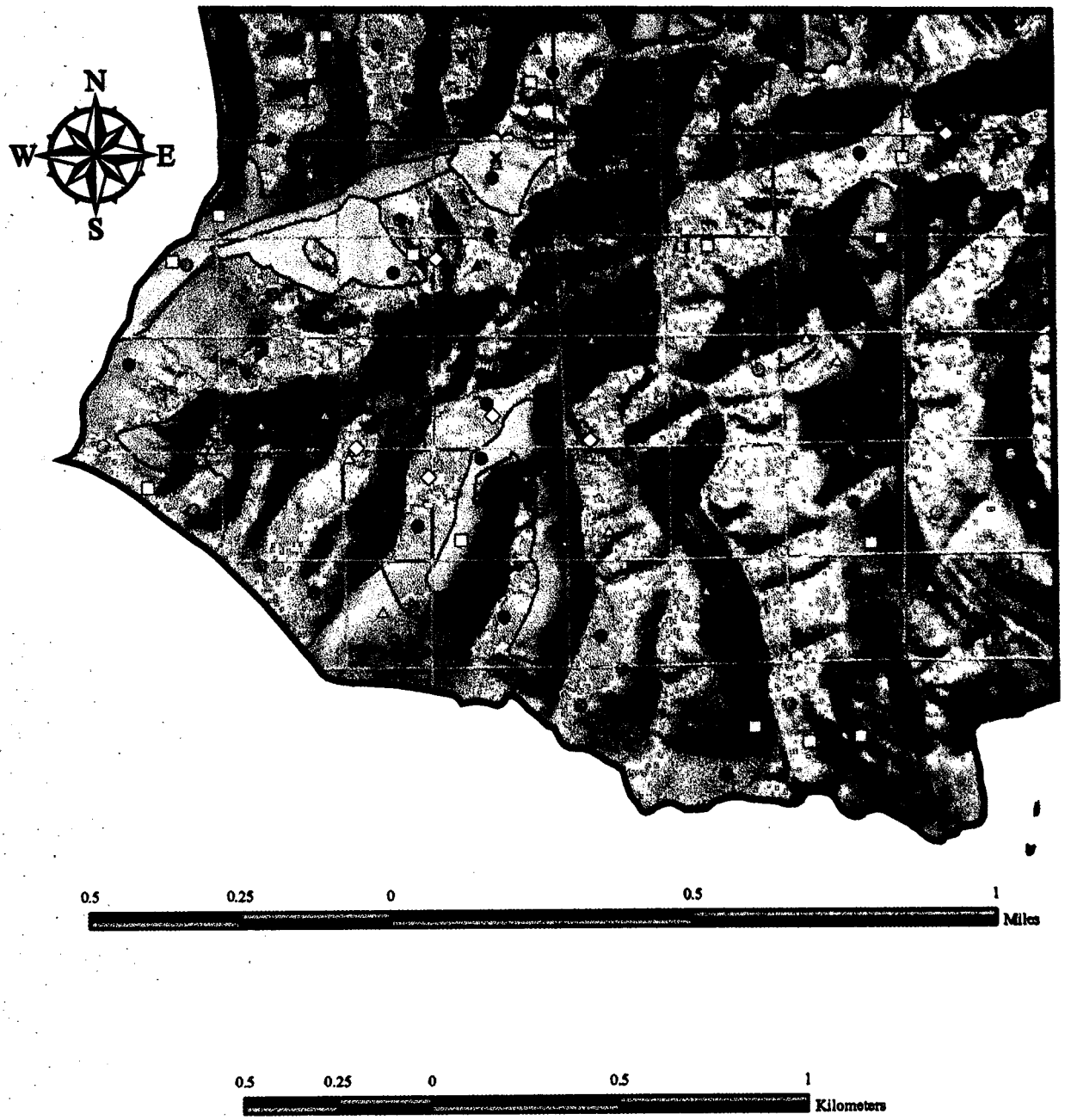
Site 7
Data Collection Locations
(Block 3 - Uneven-aged Management - 502 ha)

Site 8
Data Collection Locations

(Block 3 - No Harvest Management - 340 ha)



Site 9
Data Collection Locations
(Block 3 - Even-aged Management - 462 ha)



At MOFEP sites, stands with trees least likely to survive until the next re-entry in 10-15 years were selected first for harvest. Remaining stands needing regeneration were deferred to the next entry. Selected stands with site index > 55 (base age 50 years) were treated with intermediate harvesting (also called thinning) according to Roach and Gingrich (1968). These stands had high stocking rates and were made up of predominately immature sawtimber or poletimber that would benefit from thinning. Removals focused on mature trees and undesirable immature sawtimber and poles. Mature tree size class varies by site. The mature size class for red oaks was usually within the range of 18 to 22 in. (46 to 56 cm) d.b.h. while mature white oaks were usually between 20 and 24 in. (51 and 61 cm) d.b.h. The mature size class for each stand was determined during the inventory process. Stands treated with intermediate cutting in this first cutting cycle will be clearcut in later re-entry periods during this first 100-year rotation. Glades, food plots, ponds, and other amenities were managed according to the 1986 MDC Forest Land Management Guidelines (Missouri Department of Conservation 1986).

Uneven-aged Management

Uneven-aged management was also implemented using MDC Forest Land Management Guidelines (1986) with stand treatments following Law and Lorimer (1989). Approximately 10 percent of each site was designated as old growth in perpetuity, and the remaining 90 percent was managed using uneven-aged silviculture. Each UAM site was divided into management units of 20 to 80 ac (8 to 32 ha), and management objectives were set for largest diameter tree (LDT), residual basal area (RBA), and q-value. The LDT objective was equal to the desired sawtimber size objective for an identical stand under EAM. An overall RBA equivalent to B-level stocking was chosen, with adjustments made to anticipate for logging damage (Roach and Gingrich 1968). Q-value objectives for 2-in. diameter size class ranged from 1.3 to 1.7 (Law and Lorimer 1989). The target tree size class distribution for UAM was identical to the composite size class distribution across the EAM sites. Treatments on UAM sites are timed to coincide with treatments on EAM sites.

Uneven-aged management on MOFEP includes both single-tree selection and group selection for timber harvest and regeneration (Law and Lorimer 1989). Single-tree selection is used to improve stand quality and to regulate tree size distribution. Group selection is included because canopy gaps created with single-tree selection are usually not large enough to regenerate tree species that are intolerant or intermediate in shade tolerance such as most oaks (*Quercus* spp.) and shortleaf pine (Law and Lorimer 1989). With group selection, small openings are created. The guidelines we use at MOFEP recommend creating group openings 70 ft (21 m) in diameter (i.e., approximately one tree height) on south-facing slopes, 105 ft (32 m) in diameter on level areas, and 140 ft (43 m) in diameter on north-facing slopes (Law and Lorimer 1989). The total area of group openings on MOFEP sites was to be approximately 5 percent of the total area harvested during the first entry.

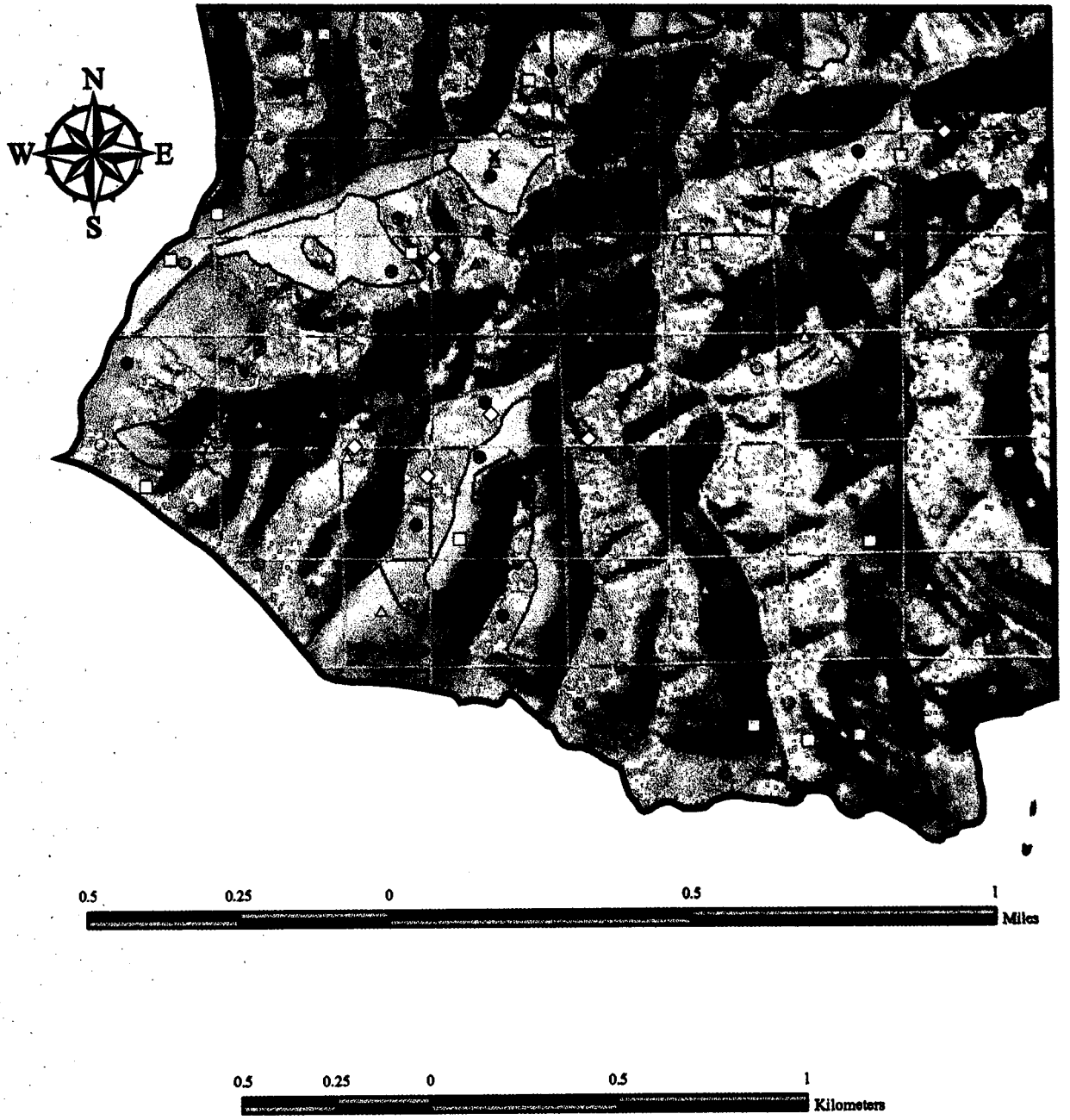
No-Harvest Management

Sites under no-harvest management are not manipulated. Natural catastrophic events, including tornadoes, fires, insects, or disease, will be treated as if on any other State-owned forest land, except that salvage harvests will not occur. Wildfires will be suppressed and areas will not be exempted from control measures applied to surrounding areas in the event of a large-scale damaging insect outbreak. This treatment serves as an experimental control treatment in this project (Sheriff and He 1997).

Implementation

The best experiment can be designed to answer a hypothesis, but if the experiment is not conducted the hypothesis will remain untested. During the summer of 1991, pre-treatment data collection began for many of the ecosystem component studies, and it continued until May 1996. From May to October 1996, commercial timber harvest was done on the even-aged management and uneven-aged management treatment sites. Removal of non-merchantable stems marked for slashing according to the silvicultural prescriptions occurred during or after commercial harvesting and was finished in May 1997 (Brookshire *et al.* 1997). For site 7 on Peck Ranch, slashing was done concurrent with the commercial timber harvest. Due to safety concerns during the harvesting operation, many principal investigators did not collect data during this period. Data collection resumed in

Site 9
Data Collection Locations
(Block 3 - Even-aged Management - 462 ha)



May 1997. Nearly 5,896,000 board feet of commercial timber were removed from these six sites during this 1-year period (table 1).

A unique feature of MOFEP concerns the protocols for the even-aged management and uneven-aged management treatments. Forest managers were allowed to prescribe treatments within broad definitions using state-of-the-art practices at the time of harvest. Brookshire *et al.* (1997) described the process for developing these prescriptions for the 1996/1997 harvest period. As we learn from MOFEP studies, forest managers will be allowed to adjust their thinking and prescriptions within the broad definitions of even-aged management and uneven-aged management. The experimental design allows for this flexibility as long as harvesting of timber from each of the six sites assigned to these two treatments occurs simultaneously during the same year and period of time (Sheriff and He 1997). Natural catastrophic events, including fires, insects, disease, or tornadoes, will be treated on MOFEP sites as on any other MDC-owned forest land, but no salvage harvests will occur on the no-harvest treatment sites (Brookshire *et al.* 1997:19).

During the pre-treatment phase, 28 individual studies were associated with MOFEP (Brookshire *et al.* 1997:23) (fig. 3). It is through these studies that knowledge about the impact of forest management will be gained.

The Statistical Analysis of Data from MOFEP

Many of the independent ecological studies conducted during the pre-treatment phase of MOFEP used the randomized complete block design as a basis for their statistical analyses (Brookshire and Shifley 1997). A common analytical approach for the pre-treatment data was to use the basic two-way analysis of variance presented by Sheriff and He (1997:29-32). For data collected after the treatments were completed in 1997, Sheriff and He (1997) recommended several approaches for the analysis of post-treatment data conditional on pre-treatment information. The simplest approach is to pool the pre-treatment data within each site and to pool data from the post-treatment period, find the difference between the post-treatment and pre-treatment means by site, and use these resulting estimates in the two-way or split-plot analysis of variance approaches (Sheriff and He 1997:30-31). Sheriff and He (1997) also advocated an indexing approach for adjusting each year's post-treatment data by the pre-treatment responses, and then using a profile analysis of repeated measures (von Ende 1993). If pre-treatment data are not available, then the post-treatment data would not be adjusted in relation to pre-treatment conditions.

These approaches recommended by Sheriff and He (1997) do not take advantage of the complexity in the full data set, especially when post-treatment data are being analyzed without adjusting for pre-treatment conditions. The full

Table 1.—*Acres within each MOFEP site, assigned forest management practice, acres harvested, and tree volume (in thousands of board feet) taken from each MOFEP management unit*

Site	Acres in site	Forest management practice	Acres harvested	Volume of timber harvested in 1996/1997
1	960	No-harvest	0	0
2	1,275	Uneven-aged	876	1,146
3	892	Even-aged	304	754
4	1,186	Uneven-aged	735	952
5	775	Even-aged	256	927
6	1,086	No-harvest	0	0
7	1,242	Uneven-aged	513	1,344
8	839	No-harvest	0	0
9	1,141	Even-aged	172	773
Total	9,397		2,856	5,896

acre = 2.47 ha

repeated measures design across the boundary between pre-treatment and post-treatment cannot be taken advantage of due to the "pseudo-treatment" effects in the pre-treatment data (Sheriff and He 1997:31). Therefore, further statistical development must occur to incorporate this complexity in the full data set. ortunately, work is occurring in this area, and Reiczigel (1999) showed that this problem may have a potential solution. This approach breaks the analysis into two steps. In the first step, the repeated measures from individual sites are examined. The time series coverage for a site is examined to determine the baseline length, the minimum or maximum value, and the time to this value. This is done using moving averages. In the second step, standard statistical methods are used to compare differences among groups or treatments. At this time the method of Reiczigel (1999) has not been fully explored to ensure that it is directly applicable to the MOFEP case, but it is encouraging to see such developments. Future statistical development will need to occur throughout the life of MOFEP to provide more information that is more useful to natural resource managers.

Beyond the null hypothesis testing approach, methods of statistical estimation and statistical modeling can also be quite useful. Vangilder (1997) used both hypothesis testing and statistical estimation in examining acorn information from MOFEP. Through the estimation approach, estimates of precision for parameter estimates can be determined by site. Using statistical modeling with these data, one can explore ecological theory to determine factors influencing these estimates (Shenk and Franklin 2001). Information-theoretical methods may be particularly useful for model selection and in data exploration for hypothesized relationships (Burnham and Anderson 1998). Models that show relevant hypothesized relationships are the basis for further research and experimentation.

The Interpretation of Results from MOFEP

Depending upon the researcher's desires, the proper statistical analysis should lead to proper interpretation of results for the intended audience. Sheriff and He (1997:33) addressed the issue of whether blocks were fixed or random effects (Littell *et al.* 1996) when interpreting results for decision making that would affect forests in the Missouri Ozarks (Xu *et al.* 1997). This issue is important to the usefulness of results.

The interpretation is also restricted by the temporal nature of MOFEP. Because MOFEP may have a life of 300 or more years, data and results interpreted during this first phase should not be considered the definitive answers to forest management issues. In fact, these, results may not be good long-term predictors of impacts that the three forest management practices might have upon forest ecosystems. Temporal variation due to abiotic and biotic factors during this relatively short period in the life of MOFEP may be unusual and have only immediate impact. Therefore, the commitment to MOFEP and its long-term nature should be emphasized for gaining reliable knowledge about long-term effects.

If we keep the long-term nature of MOFEP in mind, short-term results and interpretation can help us develop predictions that can facilitate learning in the future. Results from hypotheses tested as well as results from statistical estimation and modeling can be used to develop sound predictions for forest managers. These predictions can also be used as hypotheses or models for development of theory that can be tested during the life of MOFEP. Forest managers should use these predictions in their planning for each re-entry (future harvest). Models can be built based upon this information to test different adjustments to silvicultural prescriptions within the even-aged management and uneven-aged management protocols. As forest managers focus on a specific objective for their management, they can use adaptive management procedures (Walters 1986).

LESSONS LEARNED FROM MOFEP

MOFEP has already taught us many lessons. Our decision to design MOFEP as an experiment has proven to be a vital one. By developing MOFEP as an experiment as opposed to an observational study, we are able to test hypotheses instead of confirming or developing hypotheses. Through hypothesis testing we are able to learn much more rapidly than through a succession of observational studies and model-based predictions. In a forest ecosystem where the generation time is long, observational studies and model-based predictions require

significantly more time to gain knowledge about the impact of forest management. The experimental approach allows us to determine cause-and-effect relationships.

Because of randomization and replication in assigning forest management practices to landscape scales typically used by forest managers (i.e., MOFEP sites or compartments), the inferential basis for individual studies is applicable at a scale usable by and familiar to forest managers. Studies that focus on timber stands within a forest management unit, such as soil compaction studies (Ponder 1997), the DEMO project with 420 ac (180 ha) for each replication of six treatments (Franklin *et al.* 1999), and the study of environmental effects at the stand level in Arkansas (Baker 1994), are limited in their scope and meaning to forest managers. These smaller scale studies can provide data only at a limited spatial scale, which may not be applicable at larger ecological scales. MOFEP's broader scope allows forest managers and wildlife scientists to learn about how larger forest communities react to operational forest practices at a scale relevant to the forest community and management. Replication of forest management practices allows comparisons across a wider range of forest conditions. Randomization ensures that biases occur by chance.

Lessons learned by mistakes are often memorable and important in helping others. In designing MOFEP, we made many memorable errors that may be valuable lessons for others. Not enough time seems to go into planning any project or study, which usually is evident to investigators after a study is implemented and a field season or two has passed. At that point, it is not easy to go back and redesign the study, but one must go on with the established protocol and make recommendations to future researchers. This is also true for MOFEP, but we are fortunate to be able to offer some wisdom now.

Several problems have become evident. The first of our problems concerns the selection of experimental units. In the late-1980s, most forest management units (administrative compartments) were under active forest management. Few sites were available that met our criteria for selection as satisfactory experimental units (Brookshire *et al.* 1997:2). Therefore, the number of replicates to which we could apply treatments was limited. MOFEP probably consists of the last nine or so sites that met our criteria for selection in the southeastern Missouri Ozarks. The lesson learned was the value of having large areas where active natural resource management is not conducted, except under a designed experiment or adaptive resources management process (Walters 1986, 1993).

Another lesson we have learned concerns the selection of studies conducted on MOFEP sites. Rigorous planning for the integration of information derived from different ecosystem component studies was not done before pre-treatment data collection began. Therefore, the task of data integration from different MOFEP studies has not been easy (Gram *et al.* 1997). Our failure was in the selection of sampling scale and coordination of sampling plots among individual studies. Several of the studies required that researchers restrict their sampling to limited locations within a site so that it would be practical to accomplish their work at a reasonable cost (e.g., Marquis and Le Corff 1997, Renken 1997, Weaver and Heyman 1997). As MOFEP progresses, we also see a need for additional studies that were not begun during the pre-treatment phase. The MOFEP steering committee has identified several of these studies—for example, on nutrient cycling (Missouri Department of Conservation 1999).

To avoid these problems of sampling scale, coordination of sampling plots, and the need for additional studies, a modeling approach might have been developed during MOFEP's planning phase. Ecological models could have been developed to examine ecosystem components, such as vegetation, animals, and abiotic factors (e.g., microclimate and soil nutrients), that might be sensitive to different forest management practices. Interactions of ecosystem components could have been built into these models to examine how a single component affects other components. These models could have been developed based on knowledge derived from the literature and through principal investigators developing hypothesized ecosystem linkages from ecological theory. During these modeling exercises, important ecosystem components could have been identified to ensure that critical components would be studied to decrease our uncertainty of their value in the forest ecosystem complex. GIS-ecosystem modeling could also have been used

their prescriptions of uneven-aged management and even-aged management, and to compare outcomes from these practices with those of the no-harvest management option. The results and lessons from MOFEP can be used by other researchers and managers to design similar management experiments. The key is commitment to doing long-term management and research so that learning can occur as rapidly as possible. This commitment requires many resources, such as available landscapes for conducting these studies, financial support, and enthusiasm to learn and apply the knowledge gained.

The lessons we have learned from MOFEP can readily be applied to any ecological study of management practices (Resetarits and Bernado 1998). These issues are not unique to MOFEP, but they are common to all large-scale experimental research projects (Brown 1998). The shortcomings, such as heterogeneity within blocks, low statistical power, brevity of our pretreatment data collection period, lack of temporal variation, and potential problems with integration of studies, that we have experienced with MOFEP do not detract from the overall benefits of conducting this large-scale experiment. MOFEP provides an extremely valuable examination of hypotheses concerning the impact of management practices in the Missouri Ozark forests. Cause-and-effect relationships are being determined—relationships that could only be hypothesized through observational studies. Instead of guessing that forest management has a certain impact, we will be able to demonstrate it or show that it did not occur across replicated sites. This knowledge will aid forest and wildlife managers in the future as they perpetuate the Missouri Ozark forests in a sustainable state.

SUMMARY

MOFEP is a unique ecological study. It is designed as an experiment to evaluate changes in ecosystem components as impacted by different forest management practices. The experimental treatments are three different forest management practices advocated for sustaining an oak-hickory forest in the southeastern Missouri Ozarks: (1) even-aged management, (2) uneven-aged management, and (3) no-harvest management. The experiment is occurring at a large landscape scale typically used as administrative units in managing forests under the ownership of the Missouri Department of Conservation. These forest management units, which are used as experimental units in this project, are normally over 600 ac (242 ha) in size. For MOFEP, we are using nine of these sites, which are all over 772 ac (312 ha). These sites were placed into three homogeneous blocks. The randomized complete block design was used to assign treatments within blocks.

Another unique feature of MOFEP is that forest managers can adjust their state-of-the-art application of the three treatments as they learn from this project or through other sources. Therefore, the even-aged and uneven-aged management practices will reflect state-of-the-art application at the time of re-entry for timber harvest. This feature is necessary to allow forest managers to learn from their experiences and adjust their practices. Therefore, results from MOFEP will be a record of how changes in forest management practices as applied by MDC have impacted the ecosystem components being studied.

The necessary ingredient to maintain MOFEP as a successful long-term management-experiment is commitment. Investigators, administrators, and forest managers must maintain their long-term commitment of resources (financial support and land) and interest in this project. Otherwise, if MOFEP is stopped because of the lack of commitment, the investment in understanding the impact of the three management practices on Missouri Ozark forests will be lost. MOFEP has a theoretical life of three full rotations of each management treatment. If a rotational period is considered to be 100 years for the oak-hickory forest, then the life of MOFEP could extend 300 years. This length of time is mind-boggling, but the knowledge gained through this long-term experiment will be extremely valuable throughout the life of MOFEP. Therefore, this information will be invaluable to wildlife and forest managers for generations yet to come.

Lessons learned from our experiences with MOFEP will help others as they implement large-scale experiments in other ecosystems. One of the key lessons we learned was that adequate planning helps avoid many shortcomings and problems. Planning these types of studies requires a team effort to ensure that all aspects of a project like MOFEP are taken into account (Resetarits and Bernardo 1998). The most important lessons learned from MOFEP

concern the value of the experimental approach for gaining knowledge for management. Determining the cause-and-effect relationships of management actions to response in ecosystem components provides information about the impact of an action without continuously guessing about the hypothesized impact. Planning and use of the experimental design methods will ensure that ecosystem projects will succeed and that knowledge will be gained from all aspects of these projects.

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