**Grassland Monitoring Team: Updating the Prairie Adaptive Management Plan**

*A Case Study from the Adaptive Management Review Workshop*

*February 24-28, 2020, La Crosse, WI, USA*

*Sponsored by the USFWS National Conservation Training Center*

Authors: Marissa Ahlering[[1]](#footnote-0), Daren Carlson[[2]](#footnote-1), Sara Vacek[[3]](#footnote-2), Jonathan W. Cummings[[4]](#footnote-3), Mike Larson[[5]](#footnote-4), Jill Gannon[[6]](#footnote-5), Laura Dee[[7]](#footnote-6), Fred Harris[[8]](#footnote-7), Cody Okeson[[9]](#footnote-8), Hugh Ratcliffe9, Aaron Schwartz[[10]](#footnote-9), Michael C. Runge[[11]](#footnote-10), Angela M. Romito[[12]](#footnote-11).

# Executive Summary

Land managers in western Minnesota want to maintain or improve the quality of native prairie remnants which requires disturbance, primarily fire or grazing, to prevent establishment by undesirable herbaceous and woody plants. To address uncertainty about the effectiveness of disturbance practices and how often they should occur an adaptive management approach was undertaken.

The original plan (see the GMT project record) focused on assessing resting, burning, grazing, or a combination of burning and grazing within three year management and monitoring cycles. The plan continues as interest, investment, and need for effective management of northern prairies continues. Revisiting the plan reaffirmed the question about what actions are most effective and where. It also produced a number of questions to address further regarding how to improve the efficiency of learning from monitoring, how sensitive recommended actions are to objective weights, and how to improve communication. The GMT will have additional meetings to finalize the set of system states and alternative models to evaluate going forward and recently hired a post-doctoral researcher to update the model structure and to help answer these questions.

# Review

## Decision setting

Land managers with the U.S. Fish and Wildlife Service, the Minnesota Department of Natural Resources, and The Nature Conservancy in western Minnesota want to maintain or improve the quality of native prairie remnants on lands they manage. Prairie remnants require disturbance, now implemented primarily by fire or grazing, regularly enough to prevent establishment by undesirable herbaceous and woody plants. There was uncertainty about the relative effectiveness of these disturbance practices, and how often they should occur. To address this uncertainty an adaptive management approach to the implementation and monitoring of prairie practices was taken.

## Summary of the original adaptive management structure

An overview of the project and its history can be found in the Grassland Monitoring Team (GMT) Project Record. The original framing of the problem produced in 2007 was focused on maintaining and enhancing the competitive ability of native plants. The management actions included resting, burning, grazing, or a combination of burning and grazing within three year management and monitoring cycles. Monitoring was designed to record what management action occurred and the state of a prairie at the beginning and end of the three year cycle using a constructed scale combining the percent native cover, woody vegetation presence, and the number of native indicators present.

## Implementation and outcomes

The structure produced from the original framing has largely been followed, in that selected sites are monitored on a 3 year cycle and results are input into an AM model which provides management recommendations to managers. However, the managers have not always been implementing the recommended actions, the pace and application of learning has been somewhat hindered by assumptions made in the original model development, and an associated inability to address questions identified later during implementation of the project, and the GMT is not confident that management costs are included appropriately in the framing due to the frequency that no action is recommended.  
  
As originally framed, the adaptive management structure aided in comparing the effectiveness of management actions, but seemingly was not set up to directly elucidate the mechanisms behind any differences in the performance of these management actions and each of the 20 system states were largely treated independently. For example, the model seems to have been developed in a manner that is agnostic about why a particular management action is effective in one state or another. As a result, rather than being able to learn, for example, that any site with woody vegetation is best treated with fire, the model structure has limited ability to use knowledge that fire is best for woody vegetation management in one system state and apply that to another. Learning therefore progresses most quickly, and the best management action for each system state is best identified, if observations occur in each of the 20 system states.   
  
There also does not appear to be a mechanism for selecting a management action to account for the potential long-term benefits from learning. To maximize the pace of learning it can be beneficial to select sub-optimal actions in the short-term if it will provide information that enables the selection of more effective actions in the long term. The original model development seemingly did not select actions based upon their long-term benefit, or periodically select sub-optimal actions to learn the performance of unobserved actions. In addition, the relatively similar expected state transition probabilities of the uninformed model, as well as the likely elimination of more costly actions from selection, may have limited the speed or extent of exploration across the full set of available management actions.

The starting state of a prairie has a strong influence on later states, and there is a high probability no state transition will occur regardless of management action. This slows the learning process, and much of the learning since the project was initiated has occurred external of the adaptive management framework as originally conceived. That is, rather than resulting from updating the uncertainty within the adaptive management cycle, separate analyses of the monitoring data have produced more substantial results (Ahlering et al. 2020).

# Diagnostic Evaluation of the Decision Components

## Problem context

Reexamining the problem produced the problem statement and background below:

What management actions should a land manager take on remnant tallgrass prairie to obtain high quality prairies across Minnesota given uncertainty about the effectiveness of alternative management actions?

Remnant tallgrass prairie in Minnesota is threatened by encroaching invasive species, particularly cool-season introduced grasses (e.g. *Bromus inermis, Poa pratensi*s) and woody vegetation. Managers have available an extensive suite of management options. However, uncertainty remains about the most effective implementation of tools to reduce invasive species without harming desirable native species. There also is uncertainty about how often those tools should be applied to be most effective. In addition, managers know that the starting condition of a prairie will affect the management outcome, but are unsure of whether there is a threshold at which it would be impossible or too costly to recover a prairie using routine management.

The problem statement and background above are largely a restatement of the original problem statement provided in the GMT project record. An alternative problem framing that addressed how to allocate management and monitoring resources across the northern prairie landscape was considered. However, because that form of decision making is already occurring to some degree, and also because individual agencies act independently which limits coordination at the landscape scale an allocation focused decision framing was deemed to be less pressing.

## Objectives

The GMT project record provides the following statement of objectives for the GMT adaptive management project:

The partners in this project have overlapping goals, but it should be noted that each of us has some specific goals that are not addressed with this effort. Within the context of this project, the following objectives apply across all ownerships and participants.

* Maintain or increase the percentage cover of native prairie vegetation relative to invasive/exotic vegetation.
* Maintain the floristic diversity of native grassland ecosystems.
* Minimize the percentage cover of invasive/exotic vegetation.
* Maintain the structural diversity of native grassland ecosystems.

Discussion of these objectives during the double-loop process led to a possible simplification of these four objectives to two; native species richness (as measured by # or proportion of indicators species) and relative abundance (as measured by % cover of native). More discussion is needed here to determine whether a change is warranted.

While this statement of objectives captures the values of the GMT, the performance metrics associated with these objectives were too complex. They were too complex in that these objectives were combined and summarized into 20 possible systems states (Table 1) to capture the achievement of these objectives in a management unit, which slowed learning. The adaptive management framework was developed in a manner that learns primarily through observations within a system state. Management units infrequently transition from one system state to another, and the large number of states led to few observations in many of the system states which is likely making it difficult for the model to update state transition probabilities over time.

The discussion of objectives also produced two strategic objectives of the Grassland Management Team (GMT) adaptive management effort. The first is to create and support partnerships between the members of the GMT to maximize accomplishments. The second is to expand beyond the current set of management units, by creating support for prairie adaptive management built through learning and successes from the past 12 years.

## Alternative actions

The management alternatives assessed as part of the GMT process include five management tools and two disturbance frequencies. Management treatments include fire, grazing, a fire-graze combination within a year (both), and a fire-graze combination across years. A year without treatment is termed a rest year. Disturbance frequency levels describe how often a treatment is applied; a low disturbance would be zero or one treatment during the three year period, while a high disturbance frequency would be two or three treatments during the three years.

One difficulty experienced with the original set of alternatives was a lack of specificity in the timing of treatment. The model did not require or specify when in the three year cycle for the treatment to occur. It is hypothesized that the number of years since the last disturbance impacts the treatment result. Therefore, the timing of treatment and monitoring requires further analysis and possible revision.

In addition, the timing of treatments within a year is at the discretion of managers. This flexibility may be necessary to ensure implementation, but the effectiveness of treatments is likely influenced by when they occur during the year, and further examination is necessary.

## Predictive models

While the models are able to predict future system state, and learn from the monitoring of system state over time, they lacked detail about the mechanisms driving state transitions. The only driver of subsequent system state in the predictive models was the current system state and whether treatment occurred. A work around enabled some learning from management units (MU) in similar, but not identical, system states treated in the same manner. However, this approach limited the pace of learning because in practice essentially every system state and treatment seemingly needed to be observed many times to reduce the uncertainty in transition probabilities. That is, a series of nearly independent models was used for each system state with limited ability to learn from models of other system states.  
  
In addition, the models utilized to date for the GMT project were not transparent nor documented in a manner that supports easy understanding of the updating process. The GMT was not able to describe how the models learn based upon monitoring, and the double loop GMT coaches were unable to fully decipher the workings of the modeling in the time available.

It seems that the uncertainty was modeled as structural uncertainty only, with two alternative model formulations. One model formulation hypothesized that treatment would improve the state of a treated site, and the other model formulation hypothesized that treatment would degrade a site. While the results of treatment(s) through time enabled updating the transition probabilities by learning which actions in a given system state improve and degrade that system state, learning was not differentiating between different hypotheses regarding the mechanisms governing transition of system state. This is believed to slow learning in that in practice it appears that each of the 20 system states and treatments need to be observed multiple times to provide information that updates the transition probabilities for that particular system state and treatment combination.  
  
The bulk of the resolution phase was aimed at addressing the concerns with the current modeling approach.

## Value of information

Value of information (VOI) was not calculated in the original formulation. Because the model formulation, particularly with regards to uncertainty and learning across system states, was unclear, the inputs to a VOI calculation for the original formulation were also unclear.

## Monitoring system

As designed, the monitoring program supported the original problem formulation in that partners have utilized common monitoring protocols to provide data and that data is centrally stored and used to update the models. In this sense, the monitoring program has been a success.

The primary limitation of the original monitoring system was due to the model formulation, and the lack of a power analysis appropriate for the Bayesian model system to elucidate the rate of learning under the original model formulation. While monitoring has occurred, the infrequent collection of data and the large number of observations seemingly required to impact treatment recommendations by the model formulation may have slowed the pace or extent of learning. This has led to concern that the number of system states in the model formulation, or the number of available treatments are too large. A power analysis was performed in 2012 and informed a traditional, frequentist statistical approach. A power analysis of the Bayesian model approach could have provided the GMT with clear expectations about an opportunity to weigh trade-offs between the original modeling approach vs. others (such as modeling parametric uncertainty), and provided more guidance on sampling intensity (in time and space) and learning rate.   
  
Optimization methods

As noted, the original model formulation and analysis was not fully transparent to the GMT. Based upon the project record it appears that passive dynamic optimization has been an ongoing aspect of the GMT project and the GMT recognizes this as an aspect of the model to review in the future. This optimization has aided management, and in conjunction with analyses occurring outside of the GMT, the project has achieved some adaptive management confidence and results, especially in regards to treatment frequency, but also some indication of management type..  
  
To date, the expectation is that the optimal recommended treatment is implemented at each site. The learning rate could improve if short-term suboptimal treatment practices were accounted for in the model to enable learning and long-term improvements. Additionally, it is possible that in some system states learning about the efficacy of some treatments never occurred because those treatments were never recommended. However, the recommended action is not always taken due to cost, timing, or other constraints which may have increased the variety of implemented treatments and associated learning.

## Impediments to implementation

The GMT adaptive management program has largely been implemented as planned and is ongoing with continued investment from GMT members. The decision context as originally formulated by the GMT is quite similar to the decision context elicited during the double loop process, and few concerns about the framing of the decision were raised. One concern is that costs are not appropriately captured in the model. Currently, the model’s recommended treatment, when accounting for costs, seems suboptimal to GMT members.  
  
The primary impediments identified during the double loop process were disconnects between the model development and model understanding by the GMT members. This manifested in a limited pace and extent of learning.

## Outcomes of implementation

While model weights have been slow to change, GMT members expressed confidence that monitoring has aided their knowledge to maintain or improve the condition of northern prairies.

# Diagnostic Summary

## Decision context: is the decision structure appropriately defined?

The GMT adaptive management program has largely been implemented as planned and is ongoing with continued investment from GMT members, as the interest in, and need for effective management of northern prairies continues.

## State-dependent structure: is dynamic management warranted?

It is possible to manage prairie sites on an annual basis. It is clear from prior analyses that the optimal treatment of a site is state dependent. Given the current level of uncertainty around transition probabilities, the dynamic predictive model is needed to identify the optimal treatment of a site.

## Value of information: is (single-loop) adaptive management warranted?

A VOI analysis has not been conducted, so there is not direct evidence of the extent to which adaptive management may improve conservation of these prairies. Circumstantial evidence suggests that learning can result from monitoring, and uncertainty impacts the selection of treatment plans, so there is potential that the benefits of adaptive management outweigh the costs. The collaboration that resulted from the development of the GMT project is providing external benefits as well that may sustain the program despite any potential that the VOI is low.

In addition, one unresolved question the GMT that a VOI analysis may help address, is if there are prairie conditions at which a site has become too degraded to be conserved with the set of treatments evaluated. This also includes a follow up question regarding if efforts should be focused elsewhere if such a degraded state exists or if additional more aggressive treatments should be taken at those degraded sites.

## Adequacy of resources

While there are resource limitations, the resources that are available to the GMT are sustaining the program, and are funding additional researchers to update the adaptive management framework based upon the results of this double loop process so resource availability is not a primary impediment to this adaptive management process. Management funds are available and are supporting management. The limitations that are present impact monitoring as well as monitoring data storage, management, and analysis.

## Summary

Revisiting the decision structure through the double-loop process enabled the GMT to produce a set of questions they would like to resolve. These questions are:

1. What disturbance action is most effective at improving the status of GMT sites?
   1. Does this differ by habitat quality?
   2. Does this differ by the details of the site or other abiotic factors (e.g., weather)?
   3. Does the order of events through time matter?
   4. What is the threshold for transition to rebuilding management?
   5. What is the maximum improvement possible given the action?
   6. What is the best management frequency?
2. Are we learning?
   1. AM framework
   2. Post-hoc analysis
3. How important are the objective weights?
   1. Cost objective specifically?
4. What form of output is best to communicate to managers, how can we communicate the model framework better?
5. Where should actions be taken, and not taken?
   1. What is the maximum improvement possible given the action?
6. How intensive does the monitoring need to be?
   1. What is the best monitoring frequency?
   2. How should monitoring be allocated spatially (transect vs. unit)?
7. How does transect level variability influence effectiveness at the management unit scale?
8. How best to record and assess disturbance history?

# Resolution

# Resolution Summary

While there are resource limitations, the resources that are available to the GMT are sustaining the program and funding additional researchers to update the adaptive management framework based upon the results of this double loop process. The main limitation related to available resources is that fewer sites are assessed than would be with unlimited resources for management. This is not exclusively a limitation of funds, but also personnel and equipment capacity.

## Updating system states - confirming objectives and revisiting alternatives

The discussion of objectives produced nearly the same set of objectives, but there is some ongoing question about what performance metrics can be best combined to produce a representative but minimal set of system states. With the possible simplification of the four objectives to two main objectives, we discussed using three levels of # of indicators species (0, 2, and 5) and four levels of percent cover (0-25, 26-50, 51-75, 76-100) to create 12 system states instead of 20. However, a final decision was not reached and these items will need more discussion, including assessing other metrics of prairie condition such as C3:C4 grasses.

Three aspects of alternative treatments were not included in the original formulation that the GMT would like to consider including going forward. These are: the history of treatments on a site, the timing of treatments within the annual management and ecological cycle, and the type of prairie present at a site. A site that has been grazed or burned in the recent past may respond differently to a subsequent action than one that has not. This is not currently accounted for in the predictive model. The effectiveness of grazing or burning may depend on when during the annual cycle it occurs. For example, different plant species will be affected differently by spring or fall treatments. Finally, the species present and their response to treatment will depend on the type of prairie - i.e., dry prairie, mesic prairie, wet prairie, wet meadow, or brush prairie - present at a site.

## Updating uncertainty specification - revisiting structural uncertainty

Hypotheses around three sets of uncertainties were discussed for possible inclusion in an update of the predictive model formulation. The two primary uncertainties are whether the type of disturbance (burning vs. grazing) matters and whether the frequency of disturbance (time since last treatment) matters. A simplified representation of these two uncertainties into alternative models is shown in Table 2. These uncertainties are represented by two alternative models per uncertainty in Table 2, but it is possible that additional alternative models for each uncertainty, such as separate models that include only the prior year treatment, or two prior year treatment history, may be included during future model development. The third uncertainty the GMT would like to include is whether the seasonal timing of a treatment matters. The specifics of how these alternative models would be specified or if they will be developed is unresolved.

# Summary of Next Steps

The GMT team recently hired a post-doctoral researcher to analyze past data and update the predictive models to address the unresolved management questions. This workshop, which he attended, provided much of the information this researcher will need to update the model structure but further meetings to finalize the set of system states and alternative models will be necessary.

This model update will include a power analysis to inform the selection of system states and a VOI analysis. A sensitivity analysis to evaluate the importance of treatment cost in selection of the optimal treatments, and objective weights is also of interest to the GMT.

Specific postdoctoral tasks and timelines are as follows:

**8/10/2020 to 09/30/2020:** Become familiar with current model structure and components, including Bayesian updating, transition probabilities, and model weights

* Data clean up and streamlining for model analysis and evaluation.
* As necessary, consult with original model developers and other partners familiar with the model.
* Begin comparison with NPAM
* **Deliverable:** Scoping document on findings

**10/01/2020 to 12/31/2020:** Test current model assumptions.

* Meet with GMT team to recap USFWS workshop and write up plan for modifying model
* Timestep – currently the model runs on a three-year timestep and we need to evaluate how this is affecting management recommendations. For example, it is common for prescribed burn frequencies to exceed 3 years, which might affect results.
* Similarity Scores – a component of the model is a matrix of similarity scores (reflecting how similar each 3-year treatment combination is to the disturbance frequency and management tool alternatives being addressed by the GMT framework) which was set-up based on assumptions prior to having monitoring data. Need to evaluate how this is impacting model results.
* Number of states – the current model uses 20 prairie condition states, but it is possible that this is too many. Evaluate if reducing the number of states might improve model results.
* Transition probabilities & model weights – again, these were set up based on a small amount of monitoring data. Evaluate if these should be revised using more data.
* Wet meadow systems – identify solutions to prairie systems identified as wet meadows, which are currently not well captured in the current model and protocols.
* Test other assumptions and components as identified through model exploration, consultation with the GMT Project Team and others.
* Continue comparison to NPAM model
* **Deliverable**: Analysis plan

**01/01/2021 to 03/31/2021:** Begin model construction and coding

* **Deliverable**: Brief description and schematic of model parameters

**04/01/2021 to 06/30/2021:** Evaluate other environmental variables and state metrics.

* Evaluate if model recommendations are improved with additional or different metrics such as precipitation, prairie type, type of invasives present, geographic location, etc.
* Evaluate if certain management details should be included, such as season of management or stocking rate of grazers.
* Parameters used to define states: Test how well the current metrics used to define a prairie state (e.g. Percent native, Proportion of tier 1 native indicators, amount of shrubs) capture prairie condition. Use full floristic data from the more detailed Protocol C.
* Evaluate feasibility of other metrics to define prairie quality (e.g. functional groups such as C3:C4 grass ratio).
* **Deliverable**: Analysis plan and draft results

**07/01/2021 to 09/30/2021:** Complete data analysis and begin updating model structure and platform based on analysis results.

* **Deliverable**: Final analysis results and recommended model modifications

**10/01/2021 to 12/31/2021:** Continue to update the model structure and platform; write documentation of the model

* **Deliverable**: Model documentation draft

**01/01/2022 to 3/31/2022:** Migrate AM model out of Microsoft Access into another platform; ensure reporting and documentation of model and all analyses and database.

* **Final Deliverables**: Final report(s), model, and database; draft publications.

**If time allows:** Incorporate the cost of management

* Determine if there is a more effective way to best incorporate cost for decision-making
* Compare trade-offs between management costs and ecological outcomes.

**Final deliverables**

* Invoice deliverables are due based on invoicing schedule in Section 4.2. Interim reports should summarize work completed, decisions to be made by GMT Project Team, and suggested modifications.
* Manuscript/report summarizing the outcomes of the analyses evaluating the model assumptions including all relevant tables and figures.
* Manuscript/report summarizing the outcomes of the analyses evaluating the environmental variables including all relevant tables and figures (might be included in the document above as well)
* Manuscript/report summarizing the outcomes of the cost/ecological benefit analyses and how to incorporate into the model. If time allows to assess this component.
* Updated model structure and interface that works with the data entry portal and is usable by the project coordinators to run the model on an annual basis for the participating land managers.

# Literature Cited

Ahlering M, Carlson D, Vacek S, Jacobi S, Hunt V, Stanton J, Knutson M, Lonsdorf E. 2020. Cooperatively improving tallgrass prairie with adaptive management. Ecosphere 11(4):e03095. 10.1002/ecs2.3095

Hammond JS, Keeney RL, Raiffa H. 1999. Smart Choices: A Practical Guide to Making Better Life Decisions. Broadway Books, New York.

# Tables

**Table 1. State definitions for GMT. We collapsed the higher proportions of native indicators if the percent native cover is less than 50, as the proportion of native indicators matters less when natives are not dominant.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **% Native Cover** | **Plant Community** | **Proportion of Native Indicators** | | |
| **≥0.2** | **≥0.1 to <0.2** | **<0.1** |
| >75 | Herbaceous | 20 | 19 | 18 |
| >75 | Shrub | 17 | 16 | 15 |
| 50-75 | Herbaceous | 14 | 13 | 12 |
| 50-75 | Shrub | 11 | 10 | 9 |
| 25-50 | Herbaceous | 8 | | 7 |
| 25-50 | Shrub | 6 | | 5 |
| <25 | Herbaceous | 4 | | 3 |
| <25 | Shrub | 2 | | 1 |

**Table 2. Alternative Hypotheses Matrix showing alternative model formulations resulting from possible combinations of two structural uncertainties.**

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Treatment type matters | |
|  |  | Yes | No |
| Freq of treatment matters | Yes | Y,Y | Y,N |
| No | N,Y | N,N |

# Figures

1. The Nature Conservancy, Moorehead, MN, mahlering@tnc.org [↑](#footnote-ref-0)
2. Minnesota Department of Natural Resources, St. Paul, MN, daren.carlson@state.mn.us [↑](#footnote-ref-1)
3. USFWS Morris Wetland Management District, Morris, MN, sara\_vacek@fws.gov [↑](#footnote-ref-2)
4. School for Marine Science and Technology, UMASS Dartmouth, New Bedford, MA, jcummings@umassd.edu [↑](#footnote-ref-3)
5. Minnesota Department of Natural Resources, Grand Rapids, MN [↑](#footnote-ref-4)
6. USFWS National Wildlife Refuge System, Fort Collins, CO [↑](#footnote-ref-5)
7. University of Colorado, Boulder, CO [↑](#footnote-ref-6)
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10. University of Vermont, Burlington, VT [↑](#footnote-ref-9)
11. USGS Patuxent Wildlife Research Center, Laurel, MD, USA [↑](#footnote-ref-10)
12. USFWS National Wildlife Refuge System, Chicago, IL, USA [↑](#footnote-ref-11)