Case Study: Native Prairie Adaptive Management in the USFWS Refuge System

Seeing the Whole Picture

Case Study Module E

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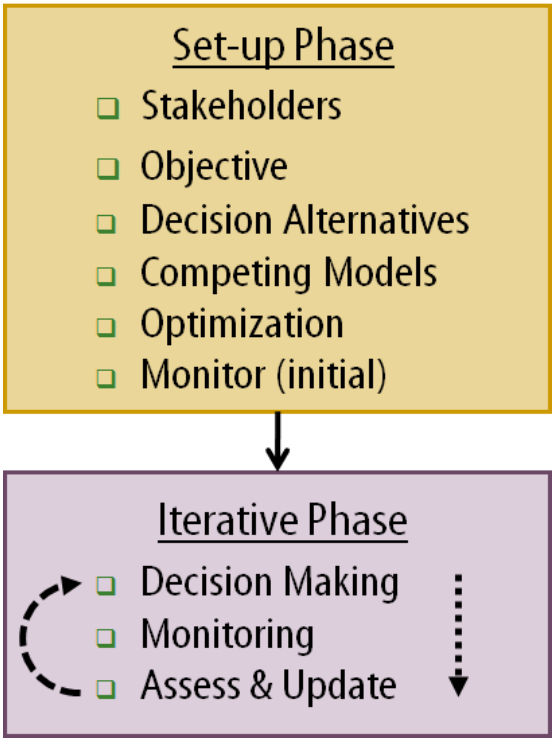
Objectives of Module

- Integrate the separate components into a comprehensive adaptive management process
  - Setup phase
  - Iterative phase
- Demonstrate the iterative cycle of adaptive decision making
- Double-loop learning
- Planning for sustainability
- Thoughts on the value of NPAM

NPAM Framework Components



Framework Components: Set-up Phase

Set-up Phase

- Stakeholders
- Objective
- Decision Alternatives
- Competing Models
- Optimization
- Monitor (initial)

Problem Bounding & Stakeholders

See Module A

- Problem
  - Loss of native prairie to two invasive grasses
  - Context
    - Service-owned lands in PPR in USFWS Regions 3 and 6
    - Decisions made annually, and at scale of individual management units (120 total) across 19 refuges
- Decision Makers & Stakeholders
  - DMs – Individual managers of each refuge
  - Stakeholders – Refuge personnel, NWRS, public

Management Objective

See Module D

- Informally stated
  - Increase the cover of native grasses and forbs at the least cost
- Formalized
  - Utility: Annual reward (0 to 1) earned for transitioning between specific levels of native prairie cover by implementing a given management action
  - Discount value: A multiplier that devalues utility the farther we look into the future
  - Objective function: A long-term sum of annual discounted utilities earned as a consequence of a sequence of actions

Decision Alternatives & Management Control

See Module D

- Management action alternatives
  - Rest, Graze, Burn, Burn/Graze combination
- Partial controllability
  - Action carried out is not always action recommended
    - Unfavorable conditions, lack of resources, etc.
  - Important to account for this source of uncertainty in dynamic forms of decision making
  - We estimated partial controllability through expert elicitation of cooperators

Models

- Link decision alternatives to management objective by predicting consequences of each decision with respect to the current and future system state
- System state structure:
  - 16 vegetation states x 7 defoliation states = 112 system states
- State and transition models for:
  - Vegetation state (four competing models)
  - Defoliation state (one model)
- Structural uncertainty
  - Competing models built around alternative hypotheses
  - Each predicts a distinct outcome for a given action
- Expert elicitation used to parameterize vegetation models

See Module B

Model Prediction

- Model input
  - Current vegetation state: native cover, dominant invader
  - Current defoliation level
  - Proposed management action
- Model output
  - Provides a distribution of predicted vegetation state in the next year in response to model inputs and stochastic events

See Module B

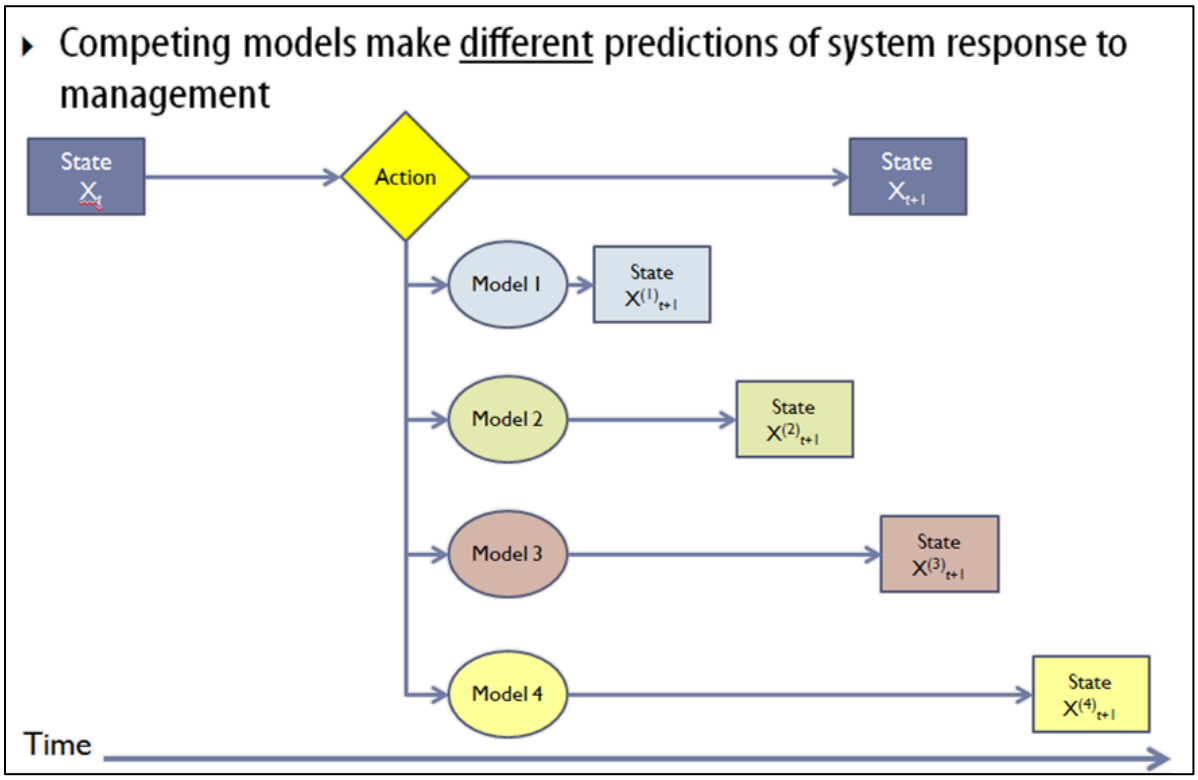
Starting States (t) and Proposed Action

NP Cover (0-30, 30-45, 45-60, 60-100):	45-60
Dominant Invader (SB, CO, KB, RM):	CO
Defoliation Level (L, M, H):	Low
Management Action (R, G, B, BG):	Rest

Distribution of Predictions (t +1)

	SB	CO	KB	RM
60-100	0	1	2	0
45-60	20	19	26	0
30-45	17	5	10	0
0-30	0	0	0	0

Competing Models



Competing Models – Different Predictions

Starting States (t) and Implemented Action

NP Cover (0-30, 30-45, 45-60, 60-100)	30-45
Dominant Invader (SB, CO, KB, RM)	CO
Defoliation Level (L, M, H)	High
Management Action (R, G, B, BG)	Burn

See Module B

Distribution of Predictions (t +1)

Model 1

	SB	CO	KB	RM
60-100	0	0	0	0
45-60	3	8	2	1
30-45	15	28	11	16
0-30	1	7	4	4

Model 3

	SB	CO	KB	RM
60-100	0	0	0	0
45-60	6	23	0	0
30-45	10	46	4	5
0-30	1	4	1	0

Model 2

	SB	CO	KB	RM
60-100	0	0	0	0
45-60	10	5	2	12
30-45	14	16	6	25
0-30	2	4	0	4

Model 4

	SB	CO	KB	RM
60-100	0	0	0	0
45-60	1	13	1	0
30-45	7	51	3	6
0-30	3	12	1	2

See Module D

Optimization: Finding the Best Management Action

- Adaptive stochastic dynamic programming
    - Integrates models and utility to find sequence of actions through time that maximizes cumulative expected utility
    - Accounts for:
        - Future dynamics of system state and knowledge state
        - Current and future expected returns (utility)
        - Degree of management control (partial controllability)
    - Produces an optimal decision table
        - Best action for every combination of system state x knowledge state
        - Current model weights determine the decision policy from within the table and describe the relative influence of each model on decision

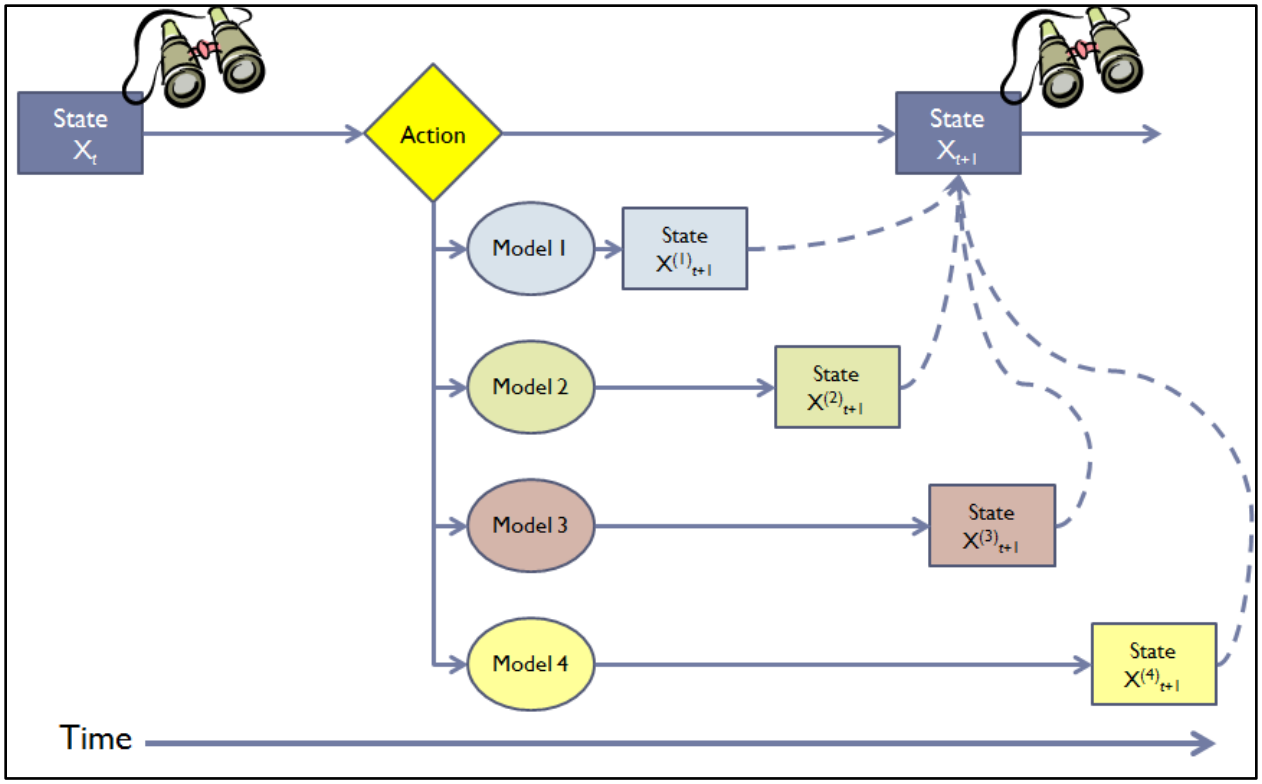
See Module C

Monitoring

- Monitoring is designed specifically to provide
    - Current vegetation state → To make state-based decision
    - Outcome vegetation state → To assess models
    - Amount of native cover → To gauge progress towards objective
- Type of monitoring that occurs
    - Management-unit level vegetation composition
    - Management actions implemented with associated details of application
- Centralized Database
    - Vegetation data
    - Management action details

NPAM Framework Components: Iterative Phase

Iterative Phase – Decision Making, Monitoring, and Updating



Iterative Phase – Main Steps

(1) Identify current decision policy given current knowledge state
(2) Recommend management action based on current vegetation state of each unit
(3) Decide and implement chosen action
(4) Predict consequences of the action under each model
(5) Monitor the resulting vegetation state
(6) Assess performance of competing models
- Compare model-specific predicted outcomes to observed outcomes and calculate model likelihoods

(7) Update model weights

Repeat Steps 1 – 7
with each decision cycle…

Decision Policy Look-Up (Steps 1 & 2)

- Step 1: Identify the current decision policy for the current knowledge state
- Step 2: Match optimal management action to current state of each management unit
  - Recommended management action for each unit
  - Best decision that can be made to date given
    - What we know about system behavior to date
    - State of the management unit to date

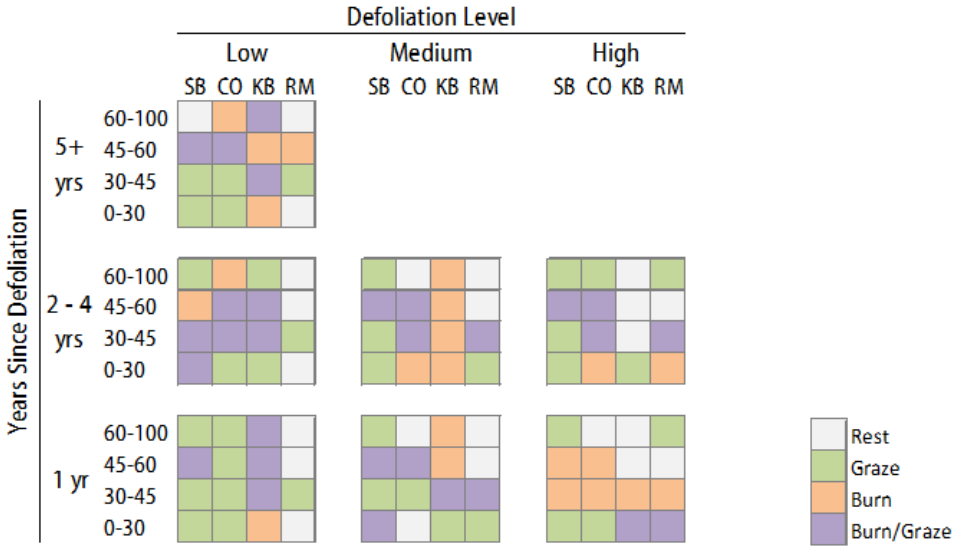
Decision Policy Best Choice

- The recommended management action from the current decision policy is the action that
  - Takes the response of the system into account
  - Recognizes current level of structural uncertainty
  - Returns information that improves future management
  - Best pursues the objective over the long term

Decision Policy – Complete Uncertainty

Knowledge State

	Model 1	Model 2	Model 3	Model 4
Weight	0.25	0.25	0.25	0.25



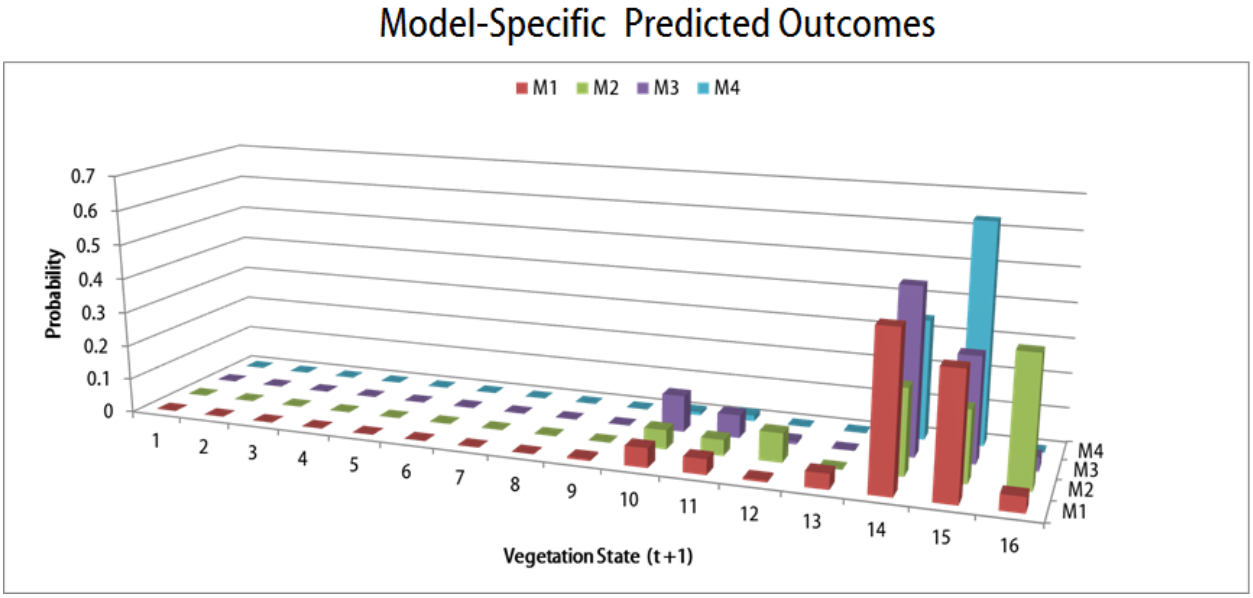
Management Decision and Action (Step 3)

- Receive recommended management action specific to each management unit (Aug 31 of each year)
- Consider recommendation, along with other information (e.g., access to cattle or burn crew, fuel load, weather conditions) and decide which management action to apply
- Carry out the management action (Sep 1 – Aug 31)

Predict Consequences (Step 4)

Model Input	
Veg State (t)	0-30, KB
Defol State (t)	1 yr | Low
Action (t+1)	Burn ★

This is an example of one unit, but we do this for every unit per its vegetation state, defoliation state, and implemented action



Monitoring Feedback (Step 5)

- After a decision is made and the action is carried out on a unit, conduct follow-up monitoring on the unit
  - Based on the belt-transect sampling of our example unit, the data are provided in terms of proportions of the four vegetation components, along with a measure of variation

	NP	SB	KB	RM
Mean	0.154	0.034	0.167	0.645
Stdev	0.061	0.034	0.045	0.073

  - We recognize that we don't observe the unit perfectly (partial observability) and construct a distribution of the observed data

	SB	CO	KB	RM
60-100	0	0	0	0
45-60	0	0	0	0
30-45	0	0	0	0
0-30	0	0	0.094	0.906

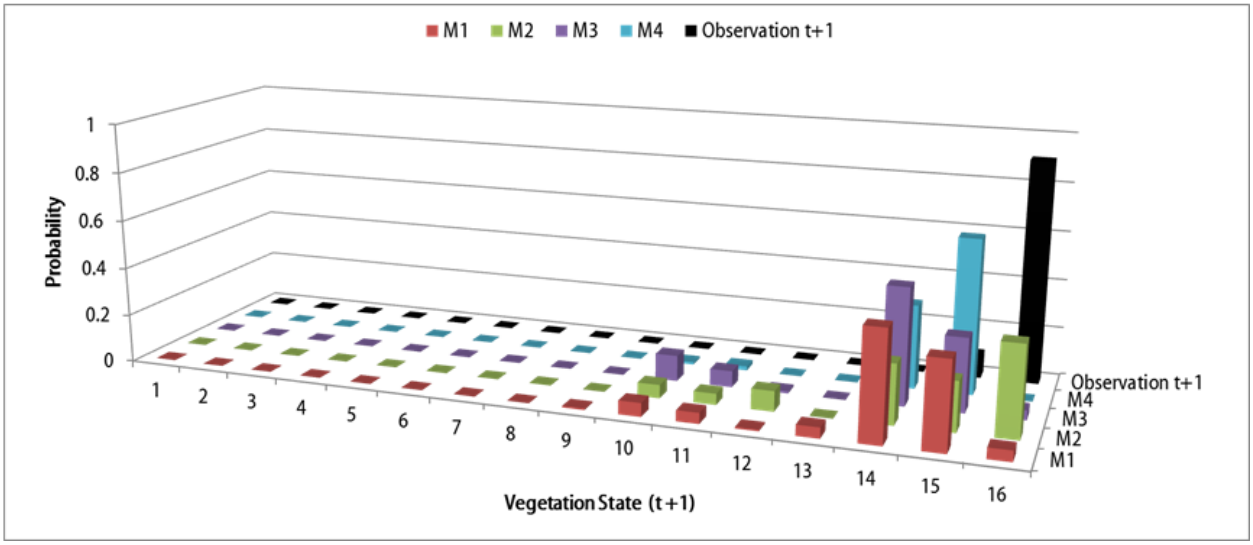
Assess Model Performance (Step 6)

Model Input	
Veg State (t)	0-30, KB
Defol State (t)	1 yr | Low
Action (t+1)	Burn

Monitoring Feedback

Veg State (t+1)	SB	CO	KB	RM
60-100	0	0	0	0
45-60	0	0	0	0
30-45	0	0	0	0
0-30	0	0	0.094	0.906

Model-Specific Predicted Outcomes and Observation Outcome



Assess Model Performance (Step 6 – continued)

- Compare model-specific predicted outcomes to observed outcome by calculating model likelihoods
  - ***Model likelihood***: The probability that the observation could have arisen as an outcome of the given model
  - Computed, per model, by multiplying the observed probability per state by the model-specific predicted probability per state and summing over the 16 states

Model	Likelihood
M1	0.0733
M2	0.3528
M3	0.0643
M4	0.0593

Update Model Weights (Step 7)

- With a likelihood for each model, we update initial model weights by applying Bayes' Theorem

- Method 1 – Sequential by Each Unit
  Go through steps 1-7, one at a time, for each unit within a management year. The posterior for one unit becomes the prior for the next unit. Complete for all units until get the final updated model weights for the current decision cycle.

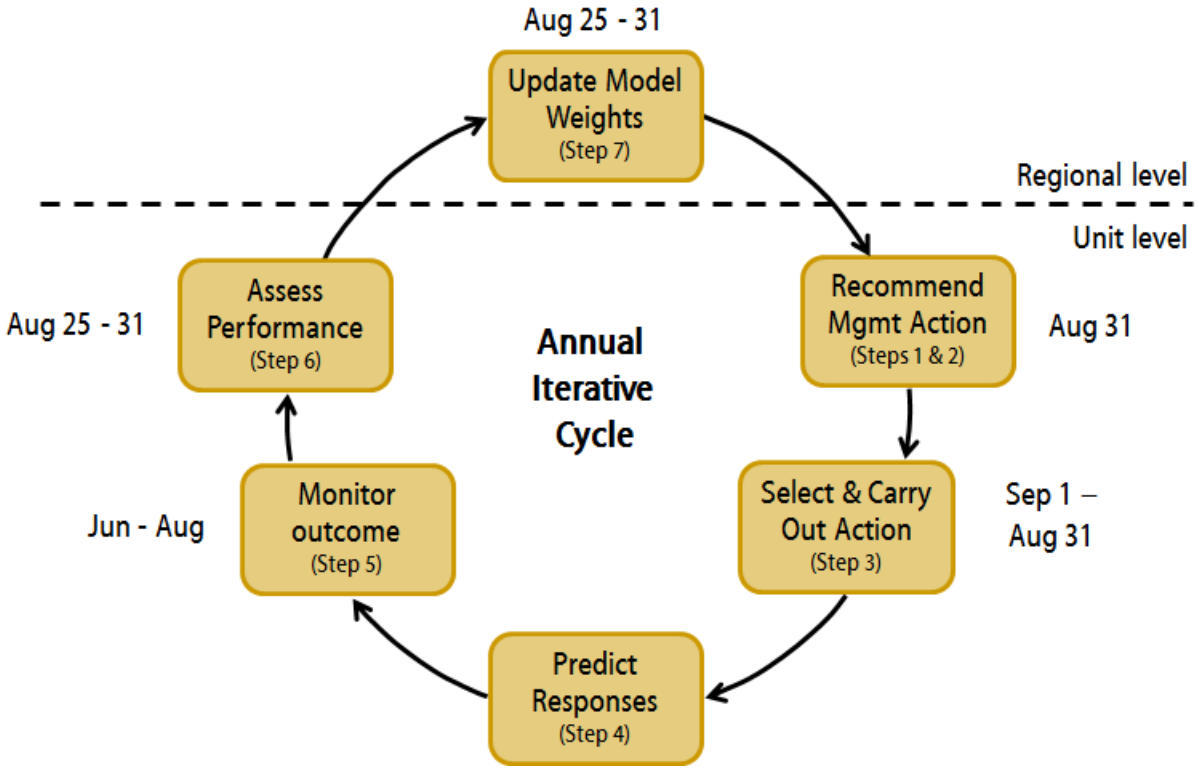
	Unit 1	
	Prior	Posterior
M1	0.25	0.1333
M2	0.25	0.6418
M3	0.25	0.1170
M4	0.25	0.1079

- Method 2 – Over All Units
  Go through steps 1-6 for each unit within a management year, calculate the median model likelihood across all units, complete step 7 one time.

Closing the AM loop: Updating Knowledge

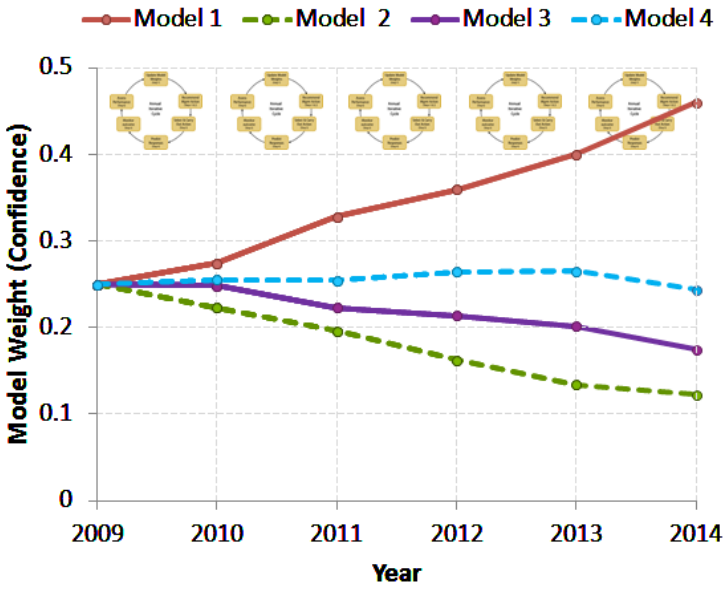
- With the updating of our knowledge state, we complete one iterative cycle
- The new model weights become the starting point for the next annual cycle of the iterative phase

Annual Iterative Cycle: Managing & Learning



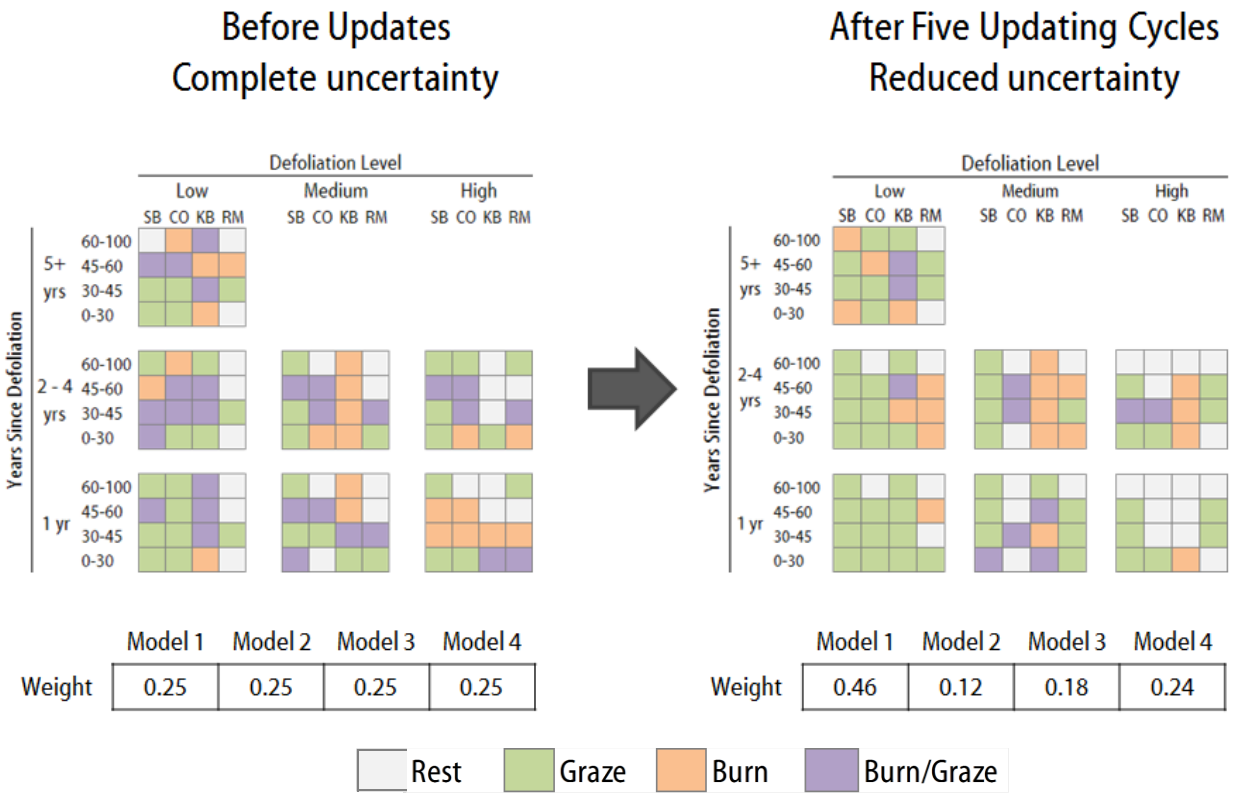
NPAM Updating Cycles

- Completed five iterations of the AM decision cycle since NPAM inception



- With each annual update,we reduce uncertainty among the competing models.
- Shift is providing greater evidence for Model 1.
- By following the framework, we know more about system behavior than we did before, resulting in improved management decisions.
- Changing the influence of each model on the guidance of next management decision via the updated decision policy

Adapting Management with Learning



The AM loop: Result

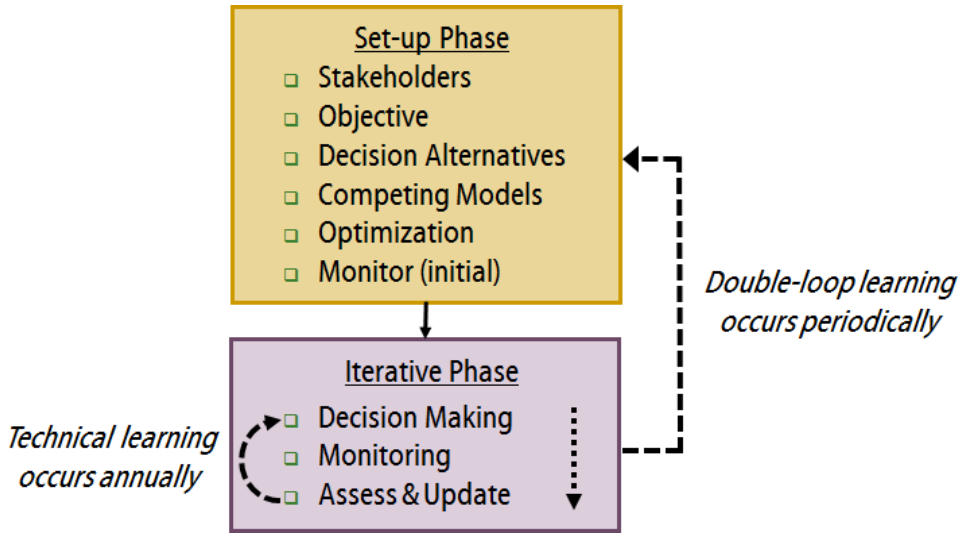
- Result of going through the annual iterative cycle
  - Reduce uncertainty by distinguishing better models from poorer models
  - Improved management decisions as better models exert greater influence on the next management decision via the updated decision policy

Value of the AM Framework

- Development of AM framework helps managers make good management decisions
  - Transparent
  - Clearly linked to management objective
  - Based on available knowledge
  - Recognize uncertainty
- Managing under the AM framework helps managers continually make better management decisions
  - Based on continually improved understanding of the system

Double-Loop Learning

- Periodically evaluate progress under AM framework
- Make modifications where necessary
  - e.g., empirical model parameters and partial controllability estimates
- Advisory Team (FWS, USGS)

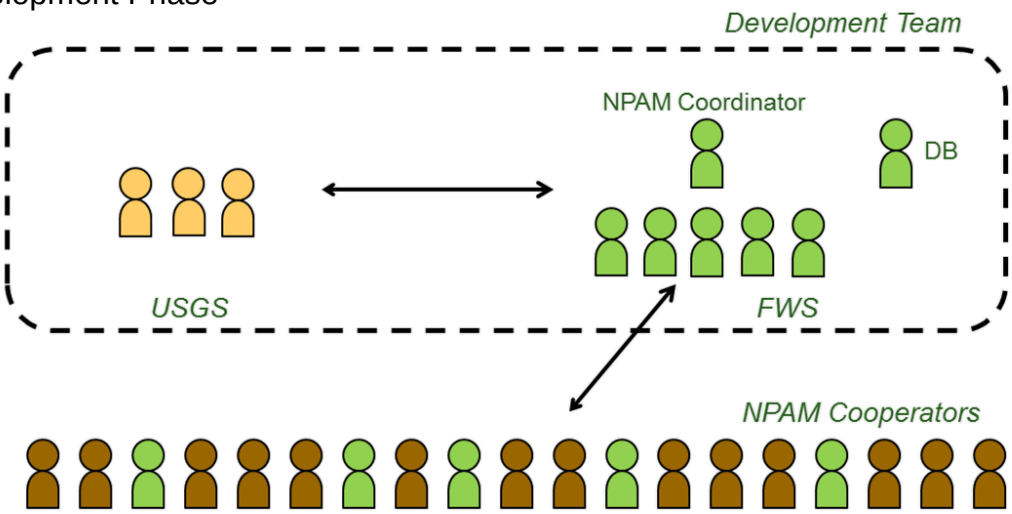


Into the Future – Continuing the Cycle

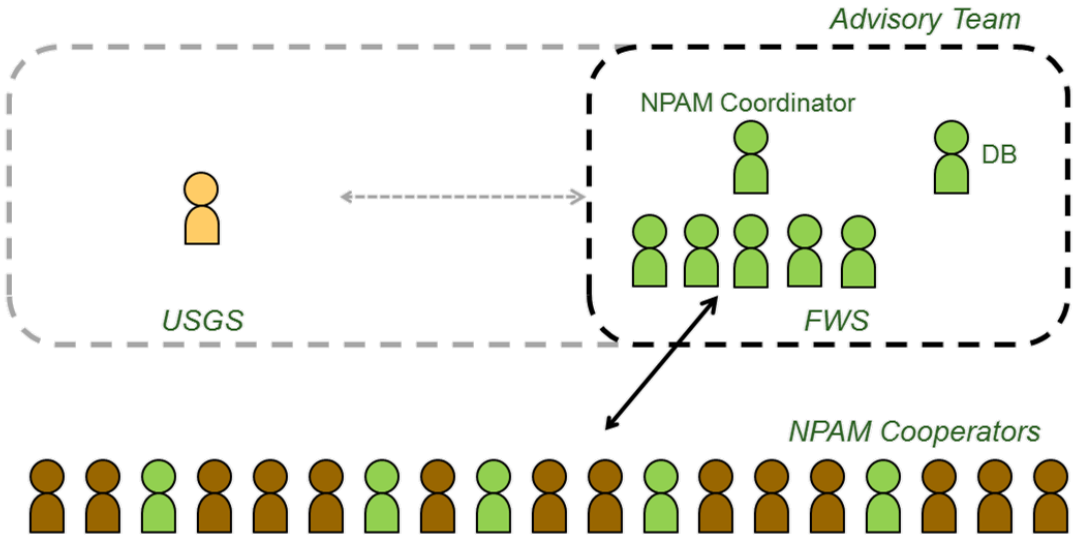
- FWS assumed operational control in 2012 and continues implementing annual iterative cycle
  - Cooperators
    - Manage, Monitor, Enter Data
  - Project and Database Coordinators
    - Update model weights and decision policy
    - Provide recommended management actions
    - Overall guidance to cooperators as needed
- USGS involvement as part of an Advisory Team
- Long-term conservation objective requiring long-term commitment → new way of doing business
- As uncertainties are resolved, management will continue
- Will be continued role for monitoring to inform decision making

NPAM Infrastructure – Governance

Development Phase



Implementation Phase



NPAM Infrastructure – Central Support

- SharePoint site for information support and data entry
  - NPAM related information stored and retrieved
  - NPAM announcements
  - Data are entered by cooperators via web portal (Hunt et al. *in press*)

NPAM Infrastructure – Protocols

- Protocol Notebook
  - NPAM Users' Manual
  - Principal document describing overall operation of NPAM
    - Roles
    - Timeline
    - Field protocols
  - Audience is cooperators and NPAM coordinator

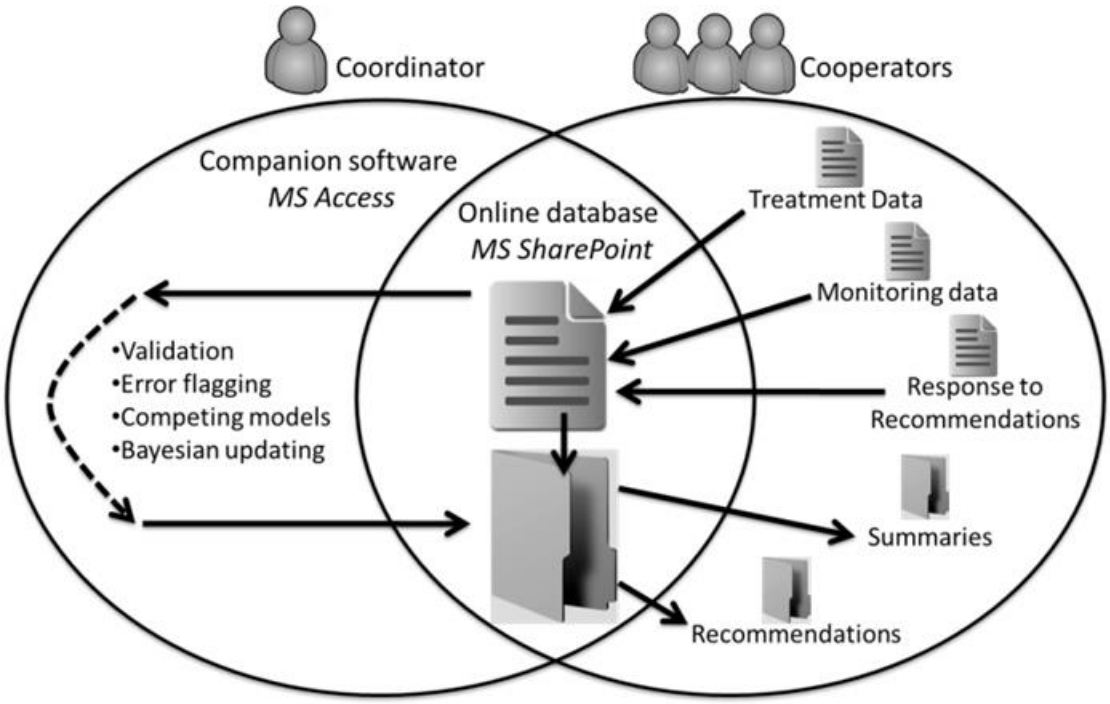
NPAM Infrastructure – Centralized Database

- Centralized database (Hunt et al. *in press*)
  - Hosted on SharePoint
  - Accessible to cooperators
  - Data entry/access is password protected
  - Observations are immediately captured and centrally stored
  - Standardization, validation, and quality control
  - Built in queries generate cooperator-level data summaries

NPAM Infrastructure – Data Processing

- Access database for NPAM coordinator (Hunt et al. *in press*)
  - Automated steps to process data
  - Prepares data for model weight updating
  - Updates model weights
  - Identifies recommended management actions
  - Generates reports and data summaries for cooperators

NPAM Infrastructure – Data Management System



Hunt et al. *in press*

Each Annual Cycle Cooperators Receive

Annual decision support for individual parcels, guided by current conditions on the ground and current understanding about system behavior

Management recommendations report

Management Recommendations for Mixed Grass Units in 2015 — Monday, February 16, 2015 4:15:00 PM

Grassland	Complex	Org	Unit	Year	NP Proportion	SB Proportion	KB Proportion	RM Proportion	Vegetation State	Defoliation Level	Years Since Level	Management Restriction	Recommended Managment Action
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 1	2014	0.30	0.27	0.40	0.04	{0-30, Co}	High	1	None	GRAZE
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 2	2014	0.39	0.19	0.25	0.18	{30-45, Co}	Med	2-4	None	BURN/GRAZE
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G26 Paddock 1	2014	0.16	0.06	0.68	0.10	{0-30, KB}	High	1	None	BURN
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G26 Paddock 2	2014	0.36	0.08	0.52	0.03	{30-45, KB}	High	1	None	REST
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G26 Paddock 3	2014	0.11	0.06	0.60	0.22	{0-30, KB}	High	1	None	BURN
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G26 Paddock 4	2014	0.12	0.18	0.48	0.22	{0-30, KB}	High	1	None	BURN
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G28	2014	0.10	0.14	0.52	0.23	{0-30, KB}	Low	2-4	None	GRAZE
Mixed Grass Prairie	ARROWWOOD COMPLEX	EDDY COUNTY WPA	Haven Paddock 4	2014	0.68	0.03	0.06	0.24	{60-100, RM}	High	1	None	REST

Each Annual Cycle Cooperators Receive

Summary of land unit conditions since NPAM enrollment

Summary of Mixed Grass States from Project Inception (2009) to Present

Monday, February 16, 2015
4:13:02 PM

Grassland	Complex	Org	Unit	Management Year	Management Applied	Management Classified	Defoliation Level	Years Since Level	Vegetation State
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 1	2009	burn/graze	N/A	High	1	{30-45, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 1	2010	rest	REST	High	2-4	{30-45, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 1	2011	rest	REST	Med	2-4	{0-30, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 1	2012	burn	BURN	High	1	{45-60, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 1	2013	burn	BURN	High	1	{45-60, SB}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 1	2014	graze	GRAZE	High	1	{0-30, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 2	2009	burn	N/A	High	1	{0-30, KB}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 2	2010	rest	REST	High	2-4	{0-30, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 2	2011	rest	REST	Med	2-4	{0-30, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 2	2012	burn	BURN	High	1	{60-100, RM}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 2	2013	burn	BURN	High	1	{45-60, Co}
Mixed Grass Prairie	ARROWWOOD COMPLEX	ARROWWOOD NWR	G14 Pasture 2	2014	rest	REST	Med	2-4	{30-45, Co}

What Native Prairie AM is Delivering

- Strong FWS ownership encouraged by design elements
  - Relevant to needs
  - Use of existing practices and conventions
  - Accommodation of constraints
  - Incorporation of preferences and knowledge
  - Preserved manager's decision making flexibility
  - Centralized database with immediate feedback/summaries (Hunt et al. *in press*)
  - Seamless integration into routine operations
- Unprecedented decision tool for resource management
  - Decision support as function of current resource state
  - Decision policies co-value learning and resource return
  - Automated system removing need for technical expertise (Hunt et al. *in press*)

➢ Science-based approach to achieving habitat conservation goals

NPAM Collaboration is Win – Win

- Refuge Cooperators
  - Build technical capacity
  - Guidance for improved decision making to help achieve the conservation objective
- USGS Researchers
  - Provide science that directly supports management
  - Work on an applied problem that actually gets applied
- ➢ More effective conservation delivery than traditional approaches that separate research and management

Spatially-distributed Adaptive Management: Benefits and Trade-Offs

- Benefits
  - Maintain flexibility of management at the station scale
  - Common protocols for monitoring and decision making
  - Broad-scale consensus on values and what is to be achieved
  - Collective learning from "replication" across system
  - Management improved locally and system-wide
- Trade-offs
  - Flexibility & Large Scales → Noise → Slower learning rate
    - Learning occurs if everyone sticks to the framework

What Native Prairie AM Has Taught Us

- Coordination
  - Timelines & standardized processes
  - Understanding of roles & responsibilities
  - Continuous communication
- Commitment to the process
  - Adherence to protocols
  - Time for learning to unfold
- Multi-partner participation

- Leaders & champions

Native Prairie Adaptive Management Team

- USFWS Development Team
  - Cami Dixon, Bridgette Flanders-Wanner, Todd Grant, Sara Vacek, Vanessa Fields, Kim Bousquet, Pauline Drobney
- USGS Development Team
  - Terry Shaffer, Clint Moore, Jill Gannon
- USFWS Refuge Cooperators – Region 3 and Region 6
- Database Team
  - Development
    - Kevin McAbee and Todd Sutherland (USFWS)
    - Sarah Jacobi and Victoria Hunt (Chicago Botanic Garden)
  - Management
    - Jennifer Zorn and Justin Dupey (USFWS)

Literature Cited

Gannon, J.J., T.L. Shaffer, C.T. Moore. 2013. Native Prairie Adaptive Management: A Multi Region Adaptive Approach to Invasive Plant Management on Fish and Wildlife Service Owned Native Prairies: U.S. Geological Survey Open File Report 2013-1279, 184 p. with appendixes, http://dx.doi.org/10.3133/ofr20131279

Grant, T. A., E. M. Madden, R. K. Murphy, M. P. Nenneman, and K. A. Smith. 2004. Monitoring native prairie vegetation: The belt transect method. Ecological Restoration 22:106-11.

Grant, T.A., Flanders-Wanner, B., Shaffer, T.L., Murphy, R.K., and Knutsen, G.A. 2009. An emerging crisis across northern prairie refuges—Prevalence of invasive plants and a plan for adaptive management: Ecological Restoration, v. 27, p. 58–65.

Hunt, V.M., S.K. Jacobi, J.J. Gannon, J. Zorn, C.T. Moore, E.V. Lonsdorf. *In Press*. A Decision Support Tool for Adaptive Management of Native Prairie Ecosystems. Interfaces.