

MINNESOTA'S WILDLIFE ACTION PLAN 2025-2035

CONSERVING HABITATS AND BIODIVERSITY

MONITORING AND RESEARCH



m DEPARTMENT OF
NATURAL RESOURCES

NONGAME WILDLIFE PROGRAM

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ECOLOGICAL AND WATER RESOURCES
500 Lafayette Road
St. Paul, MN 55155-4040
888-646-6367 or 651-296-6157
MNDNR.gov

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Cover Photos: A biologist surveys moss hummocks for four-toed salamanders, Andrew Herberg; DNR biologist conducting a broadcast survey for red-shouldered hawks, Amy Westmark

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Chapter 5: Monitoring and Research

Overview

The importance of monitoring wildlife populations has long been recognized as a critical component of wildlife conservation. This is not only true for species that are actively managed using harvest regulations, such as waterfowl, but also of rare species that may be at risk of extirpation or extinction if we are unaware of their declining status. Today, monitoring elements of biodiversity, from bees and salamanders to orchids and oak savannas, is recognized as one of the most important responsibilities of natural resource agencies.

For the third iteration of the Plan, this chapter focuses on the role of monitoring and research activities within Minnesota's SWAP. We provide an overview of our vision for what we want to achieve in the context of surveys, monitoring, and research for animals, plants, and habitats in Minnesota. We discuss the relevant questions we need answered and structure them into three pathways: baseline diagnostic information needs, determining positive actions and management activities that promote effective conservation and estimating.

Building on the two Prior Plans

Monitoring rare and uncommon wildlife species began in the late 1970s with the initiation of the Nongame Wildlife Program. Initial efforts focused on common loons, bald eagles and colonial waterbird nesting sites. Soon after, the launch of the Minnesota Natural Heritage Program placed an equal emphasis on native plants and plant communities with monitoring efforts focused on rare species such as prairie bush clover (*Lespedeza leptostachya*) and western prairie fringed orchid (*Plantanthera praeclara*). The state was well-primed to address the importance of monitoring when the state wildlife action planning process began in the early 2000s.

2005-2015 Tomorrow's Habitat for the Wild and Rare

One of the three goals established by the 2005-2015 SWAP was to "Improve knowledge about Species in Greatest Conservation Need (SGCN)". A key strategy for implementing that goal was to "Monitor long-term changes in SGCN populations and habitats". An important statewide project funded with State Wildlife Grant dollars was the completion of a statewide survey of freshwater mussels that began in 1999 and the subsequent launch of a long-term monitoring program. Other projects included continued monitoring of American goshawks, double-crested cormorant and American white pelican nesting colonies and a small but critically important Henslow's sparrow population at Great River Bluffs State Park. Monitoring habitats that rare species depend upon for their survival is equally important. Once covering nearly one-third of Minnesota, native prairie now only covers approximately 235,000 acres. The species dependent on this rare resource are among the most endangered and threatened species in the state. It was only natural, therefore, to design and launch a long-term monitoring program (SPICE; Sustaining Prairies in a Changing Environment) to track the status and trends of this critical habitat.

Minnesota's Wildlife Action Plan 2015-2025

In the second update of the SWAP, monitoring SGCN and their habitats, and applying the knowledge gained to design new management approaches or to adapt existing ones, was a major theme. The plan recognized the need to apply monitoring strategies at three levels: the Wildlife Action Network, in Conservation Focus Areas, and Species Monitoring. Numerous survey, monitoring and research projects were completed under this Plan.

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Important Definitions

Surveys

Wildlife and plant surveys are the primary tool used by the Minnesota Department of Natural Resources (DNR) and its partners to gather scientific data at specific locations and points in time. Surveys can be used to collect vital information on a variety of ecological metrics, including (1) population abundance or relative abundance, (2) population demography (e.g., survival, fecundity, dispersal), (3) habitat conditions and species-habitat relationships, (4) stressors or threats affecting species or habitats and (5) the geographic distribution of species across Minnesota. Even single surveys can be valuable especially when it leads to the discovery of rare species in new locations and informs conservation efforts.

Monitoring

Monitoring is generally defined as a structured activity in a set of sites, repeated through time. These measurements can include surveys of some species (a type of structured counting effort), evaluation of habitat features (e.g., density of trees) or assessments of ecosystem health (e.g., water quality). Monitoring is

distinguished from surveys by employing data collection methods and efforts that are repeated and standardized at some set of sites to detect changes (such as trends in abundance, species richness, or occupancy) through time or across space.

The temporal spacing of repeated sampling (e.g., daily, seasonally, or annually) and the spatial arrangement of sampling units such as the distance between and distribution of sampling locations are determined by the focal species or system and the specific questions being addressed. Key features of appropriately designed monitoring efforts are sampling designs built around a focal question(s) or objective(s), standardized efforts, repeatable procedures, well-curated data and recording of negative data (the absence of the target). The presence and absence of target species recorded through time permit the estimation of detection probability, either explicitly or implicitly, depending on the timing of recurrent surveys and assumptions about survival and movement in the study area. Accounting for detectability helps remove bias in metrics of interest (e.g., abundance, survival, etc.) and can improve trend estimates (Kéry & Schmidt, 2008).

Surveillance monitoring involves tracking trends in species, communities or habitat metrics over time to understand their status and dynamics. In contrast, **effectiveness monitoring** is structured around specific questions regarding the success of management or conservation actions intended to produce beneficial outcomes, such as habitat creation for threatened or endangered species, invasive species control or the restoration and reconstruction of native habitats or ecosystems.

Research

Research is the process of obtaining information to answer a specific question(s), involving the collection and analysis of data to test predictions or hypotheses. While the term is frequently associated with formal experimentation, well-designed surveys and monitoring efforts can also be structured to address research questions. Research approaches vary in purpose, design and methodology, yet they are not mutually exclusive and can overlap, combining elements from multiple types. The strength and utility of research increases when questions and objectives are clearly articulated and quantitatively linked to biologically meaningful outcomes. The DNR primarily engages in the following research approaches:

- **Basic or Observational Research**, which serves to expand general knowledge and understanding of natural systems and the plants and animals that are found within them. This type of research is meant to gather information by documenting characteristics, patterns, trends or species within ecological systems and may be used to inform conservation actions. An example would be a survey to detect the presence of the plains pocket mouse (*Perognathus flavescens*) on the property of the Twin Cities Army Ammunition Plant in Ramsey County, Minnesota.
- **Applied Research** is defined by its purpose for solving practical problems or informing decision-making in natural resources. While not all applied research is experimental, many applied studies employ formal experimental designs. For example, testing whether prescribed burning or goat-grazing increases native plant and pollinator species richness in grassland habitats and measuring the magnitude of those changes compared to untreated controls constitutes applied research.
- **Experimental Research** involves intentional manipulation of variables through controlled interventions, often including randomization, replication, and pre- and post-treatment measurements.



Photo: A biologist surveys moss hummocks for four-toed salamanders, Andrew Herberg

While experimental research can also fit under the umbrella of being applied, some is purely theoretical. An example would be the use of a Before-After-Control-Impact (BACI) design to assess the effect of cattle grazing on composition of the native plant community or on reproductive success in prairie obligate birds.

- **Mechanistic Research** seeks to answer why patterns in nature occur, focusing on identifying underlying biological or ecological processes driving patterns that we see in nature. An example might be a study to determine the relationship between coyote abundance and snowshoe hare survival to understand how predation pressure influences their population and recruitment.

Surveys, monitoring and research are interrelated tools essential for understanding and managing ecological systems. Each plays a distinct yet complementary role in collecting and interpreting ecological data. Surveys are the primary method for gathering measurement data at specific locations and times, often used to detect the presence or absence of individual species or species groups and help define species distributions and range limits.

Monitoring builds on surveys by structuring data collection in a consistent, standardized and repeatable way across time and space. This structured approach enables the detection of trends in abundance, occupancy, species richness and habitat conditions. A critical component of monitoring and survey efforts is accounting for species detectability, which improves the accuracy of ecological assessments and trend estimates.

Research addresses specific scientific questions or objectives, often through hypothesis testing or predictive modeling, and may use data from surveys and monitoring when aligned with its objectives. Research can take various forms including observational, applied, experimental

or mechanistic with each distinguished by the level of intervention and the nature of the questions asked. Together, these tools provide baseline data, reveal ecological trends and deepen system understanding to inform conservation and resource management.

Minnesota supports a wide range of terrestrial and aquatic ecosystems, which in turn provide habitat for diverse native plants and animals. These ecosystems deliver critical services, including water filtration, flood protection, carbon storage, timber production and recreational opportunities. However, they are increasingly threatened by direct and indirect stressors such as land and water use pressures, pollution, invasive species, pathogens and changes in climate and land management.

In response to these challenges, surveys, monitoring and research form the scientific foundation for biodiversity conservation and natural resource stewardship in Minnesota. Rigorous scientific approaches are critical for guiding conservation strategies, informing adaptive management, supporting technical assessments and conducting environmental reviews. Later sections of this chapter provide guidance on utilizing existing ecological data and outline recommendations for future data collection efforts.

Baseline Information Needs

The SWAP provides a framework to guide conservation efforts, emphasizing the need for data-driven decisions to protect declining and vulnerable species. The DNR has set clear goals to sustain biodiversity, identify conservation challenges and support species viability and recovery now and for future generations of Minnesotans. By systematically tracking the distribution and abundance of wildlife, particularly species with low and declining populations, the DNR can develop targeted strategies to mitigate threats to species, populations and habitats.

In order to have a starting point for assessing species and habitat status in Minnesota, we

need baseline diagnostic information about presence/absence, spatial distribution, relative abundance and population trends. The process of assigning whether a species should be considered a Species in Greatest Conservation Need (SGCN) starts with understanding the rarity, trends and threats of an animal or plant (see Chapter 2: Species in Greatest Conservation Need). It is not enough to have survey information at one location and time because species and habitats are dynamic and their status is influenced by a multitude of factors, which can be positive or negative.

Species

For the SWAP to be successful, a strong foundation of baseline information is essential. This includes comprehensive surveys to estimate the distributions of animal and plant species across Minnesota's diverse landscapes, and monitoring efforts designed to detect trends in species occurrence, abundance or relative abundance over time.

Habitats

Equally critical is the collection of habitat-use data for SGCN, especially given Minnesota's ecological diversity, which spans multiple biomes and supports a wide range of species and community types. Understanding how, when and where species interact with their habitats is inherently challenging, even for common species with relatively abundant data. For rare species, these challenges are magnified due to limited detections, sparse distribution and often cryptic behaviors, making it difficult to draw reliable conclusions about habitat associations and requirements.

Nevertheless, this understanding is vital for identifying the environmental conditions necessary for the survival, reproduction and persistence of SGCN. Moreover, a focus on SGCN can yield broader conservation benefits, as their habitat needs often overlap with those of other vulnerable, under-studied and even common species, thereby supporting more inclusive, ecosystem-based conservation strategies.



Photo: DNR biologist holding softshell turtles with transmitters that track movements and habitat use

Life History and Population Traits

These patterns of habitat use are closely linked to species-specific life history traits, such as reproductive strategies, dispersal capacities and habitat specialization. Such traits determine how resilient populations are to natural events (e.g., drought, fire regimes) and anthropogenic pressures (e.g., habitat fragmentation, pollution). This information helps predict population trajectories, assess extinction risks and develop science-based conservation strategies.

Additionally, data on population demographic status including survival rates, dispersal, migration and population viability are needed to assess the health and resilience of populations.

Stressors and Actions

Coupled with detailed knowledge of stressors facing SGCN and many other species, along with management actions available to mitigate those stressors, this comprehensive baseline data enables the DNR and its partners to identify vulnerable life stages, critical habitats and priority areas for conservation, protection, or restoration.

Surveillance Monitoring

Incorporating robust monitoring into Minnesota's SWAP is critical for sustaining wildlife and plant populations, preserving biodiversity and conserving the habitats that serve as homes for terrestrial and aquatic taxa. Surveillance monitoring establishes baseline conditions and can detect long-term trends, while effectiveness monitoring evaluates the value of conservation actions. Together, they provide the information needed to sustain biodiversity, manage habitats effectively and respond to emerging conservation challenges. In Minnesota, these monitoring approaches support the SWAP by ensuring that conservation efforts are grounded in scientific evidence and tailored to the evolving needs of wildlife and their habitats.

Surveillance monitoring focuses on understanding species, population and habitat distributions and tracking trends in various metrics through time. It provides a long-term view of ecosystem health by detecting changes in species abundance, distribution and community composition. This type of monitoring can be used to establish actionable thresholds and triggers, signaling potential ecological problems before they become critical or conditions for targeted management prescriptions (Nichols & Williams, 2006; Lindenmayer & Likens, 2010). For example, sustained declines in a SGCN could indicate habitat degradation, climate change effects or emerging threats such as disease. Surveillance monitoring also provides valuable data on habitat trends, helping natural resource managers anticipate shifts in wildlife distributions and potential barriers to conservation efforts. However, while it is useful for identifying patterns and broad-scale concerns, it does not pinpoint causal mechanisms behind observed changes in trends. In the context of trend estimation, additional limitations may include the absence of long-term, standardized data collection methods, making it crucial to establish strong roots with defensible sampling design principles incorporating sampling unit independence,

replication, and stratification among diverse biomes and habitats.

Species-level Monitoring

Surveillance monitoring may occur at the species-level across a variety of terrestrial and aquatic animal and plant taxa, ranging from common species to those that are declining, rare, or in need of further research (i.e., SNI - Species Needing Information). Of particular importance to the SWAP are SGCN, which are native animals and plants whose populations are rare, declining or at risk of decline. Also of primary focus are stewardship species, which have a stable population in Minnesota but are declining within the region. The DNR also recognizes the ecological importance of keystone species and ecosystem engineers — organisms whose roles in structuring habitats and ecosystem function make them critical for enhancing biodiversity. It is not possible for the DNR to track population status and trends of all species of animals and plants in Minnesota, so over the next 10-year cycle of the SWAP, the DNR and partners will be exploring alternative prioritization strategies for survey and monitoring efforts. Solutions may incorporate:

- Use of structured decision-making tools to guide the prioritization process (Figure 5.1)
- Stratification of species and habitats according to their conservation status (for example, as recently assessed in the s-rank process see Chapter 2: Species).
- Incorporating data emerging from parallel efforts, such as aquatic community data from the Minnesota Pollution Control Agency or participatory science programs such as the nationally known eBird (see Case Study on Participatory Science).
- Use of focal monitoring sites to sample a subset of habitat locations for a variety of animals through time, such as the Ecological Monitoring Network (see Case Study on Ecological Monitoring Network).

- Development and testing of species distribution models (Yackulic et al., 2012; Hefley & Hooten, 2016) to efficiently target potential habitat for threatened, endangered and species defined as SGCN.
- Adoption and transition from finer-scale relative abundance surveys to broader-scale occupancy designs (Mackenzie et al., 2006) to make more efficient use of limited agency resources.
- Landscape stratification with revolving spatial and temporal panels organized through time to rotate sampling and resampling efforts across all regions of Minnesota.
- Direct participatory science volunteers to monitor readily identifiable species to maximize information gain and geographic coverage given limited agency resources. It can be applied efficiently to gather broad distributional information or for targeted rare-species surveys.

Resources for conservation are chronically limited, and delays in action can push species and ecosystems toward irreversible decline. While there is debate about return-on-investment (ROI) frameworks which prioritize actions with the greatest benefit per cost (Joseph et al., 2009; Carwardine et al., 2012; Vucetich et al., 2017), there is a very strong argument made for proactive conservation (Walls 2018). This idea emphasizes conservation efforts for species and habitats before critical thresholds are met, thereby reducing extinction (or extirpation) risk and high restoration costs. Going further, Walls (2018) suggests taking actions that leverage and utilize stakeholder collaboration like participatory science initiatives and complementing time- and labor-intensive methods for long-term monitoring with alternative methodological approaches for detecting species population declines and estimating extinction risk. Although there is a large body of peer-reviewed literature on using formal decision theory and ROI approaches – often called “conservation triage” – to

prioritize conservation efforts, we still need to improve existing methods and explore new strategies to make the most of limited resources.

Participatory science, community science or citizen science, refers to programs that engage members of the public in data collection and research activities – often in collaboration with or under the guidance of professional scientists. In the field of ecology, participatory science programs have become increasingly valuable for monitoring biodiversity, tracking species distributions, assessing ecosystem health and providing outreach opportunities for various user groups. These programs harness the power of widespread public engagement to gather large quantities of ecological data across broad spatial and temporal scales that would be otherwise difficult or prohibitively expensive for agencies to collect alone. DNR sponsored examples include MN PlantWatch, the Minnesota Loon Monitoring Program, the Frog and Toad Calling Survey and the Chimney Swift Survey. In addition to generating scientifically useful data, participatory science fosters environmental stewardship, increases scientific literacy and strengthens community involvement in conservation efforts. When well-designed, these programs include standardized protocols, training for participants and rigorous data validation methods, ensuring that the resulting data can inform ecological research and natural resource management decisions.

Case Study: Ecological Monitoring Network

The DNR established the [Ecological Monitoring Network](#) (EMN) in 2017, with 544 sites across Minnesota, to track ecological change through time. The EMN provides data on the status of SGCN habitats and how those habitats are changing. This effort is being led by the Minnesota Biological Survey, in collaboration with other partners and funded by the Minnesota Environment and Natural Resources Trust Fund (ENTRF). Before EMN, there was no comprehensive statewide monitoring network to consistently measure and evaluate status and trends in native grassland, wetland, and forest habitats. This information is needed for natural resource professionals, ecologists, and policy makers to make informed land management, land use, and conservation decisions for the benefit of plant and animal SGCNs.

The EMN employs a nested plot design to sample all major habitat types across Minnesota, ensuring a statewide distribution that is independent of habitat quality or land ownership. Data collection focuses on ground layer vegetation and trees, alongside assessments of ecological factors such as deer browse, earthworms, water chemistry, prairie structure, and coarse woody debris. By 2023, 387 plots were established, including 45% in upland forests, 23% in open wetlands, 15% in forested wetlands, 12% in upland prairies and 5% in wetland prairies. Eighty-nine percent of plots are located on government owned land (20% Federal, 42% State and 17% local governments). Early findings have provided valuable insights into plant community variation across the state (see [Ecological Monitoring Network, Minnesota DNR](#)).

A few notable findings are native plant communities in northern latitudes appear to be generally higher quality than their southern counterparts. Low quality (D-ranked) prairies are more abundant than high quality (A-ranked) prairies. Wet meadows are typically either high or low quality with very few examples in the middle. Acid peatlands are almost always A-ranked. This is likely due to the sensitivity of these systems, as any disturbance likely increases pH causing the system to rapidly transition toward a wet meadow, fen or marsh-like community.

The EMN will begin its first resampling cycle in 2028 to assess how SGCN habitats have changed over the past decade. It has been noted also that this framework could be expanded to include the monitoring of animals, bringing an ecological understanding of plants and animals together.



Photo: Vegetation plot sampling, Ecological Monitoring Network

Regardless of the approach chosen, monitoring SGCN and SNI species provides baseline data to detect population changes through time, identifying organisms that require conservation attention or those that may become SGCN in the future. This process can inform near-term conservation priorities and guide targeted management actions. The DNR and its partners are actively engaged in current and planned efforts focused on species-level surveillance in Minnesota including:

- [Minnesota Frog and Toad Calling Survey](#) (DNR)
- [North American Breeding Bird Survey](#) (U.S. Geological Survey)
- [HerpMapper](#) (a variety of biologists, University personnel, and NGOs)
- [Minnesota National Forest Breeding Bird Monitoring Program](#) (University of Minnesota Duluth Natural Resources Research Institute)
- [Minnesota Statewide Mussel Survey](#) (DNR)
- American Goshawk Nest Monitoring (DNR)
- [Spongy Moth Survey](#) (Minnesota Department of Agriculture)
- Blanding's Turtle Population Monitoring (DNR)
- Timber Rattlesnake Population Assessment (DNR)
- Common Tern Nest Monitoring (DNR)
- Wood Turtle Population Monitoring (DNR)
- [Early Detection and Distribution Mapping System](#) (EDDMapS; Center for Invasive Species and Ecosystem Health, University of Georgia)
- Dakota Skipper Monitoring (DNR)
- Bat Acoustic Monitoring (DNR, USFS and USFWS)
- [Monarch Larva Monitoring Project](#) (Monarch Joint Venture, University of Wisconsin-Madison Arboretum)
- [Journey North](#) (University of Wisconsin-Madison Arboretum)
- [Integrated Monarch Monitoring Program](#) (Monarch Joint Venture)
- [Minnesota Loon Monitoring Program](#) (DNR)
- [Volunteer LoonWatcher Survey](#) (DNR)
- [MN PlantWatch](#) (DNR; see [Case Study: Minnesota PlantWatch Population Assessments](#) in Plants Sub-chapter of Chapter 2: Species in Greatest Conservation Need))
- Federally Listed Plant Species Monitoring (DNR; see Case Study: Federally Listed Plant Monitoring in Plants Sub-chapter of Chapter 2: Species in Greatest Conservation Need)
- [Minnesota Bumble Bee Atlas](#) (University of Minnesota, Xerces Society, DNR)
- Minnesota Colonial Waterbird Survey (DNR and NRR)
- [Minnesota Breeding Trumpeter Swan Survey](#) (DNR)
- [Minnesota Waterfowl Breeding Population Survey](#) (DNR and USFWS)
- [Minnesota Amphibian & Reptile Survey](#) (HerpMapper.org, Bell Museum of Natural History, and Minnesota Herpetological Society)
- [Minnesota Cricket Frog Survey](#) (DNR)
- [Terrestrial Invasive Species Participatory Science](#) (TIPS) projects (University of Minnesota Extension)

Case Study: Federally Listed Plant Species Monitoring Program



Photo: Researcher Dr. Joel Olfelt monitoring Leedy's roseroot, Derek Anderson

The DNR has been monitoring federally listed plant species since the mid-1980s. The level and intensity of monitoring has varied for each species including the western prairie fringed orchid (*Platanthera praeclara*), prairie bush clover (*Lespedeza leptostachya*), Dwarf Trout Lily (*Erythronium propullans*) and Leedy's Roseroot (*Rhodiola integrifolia* subsp. *Leedyi*) and is dependent on their life history and informational needs. Basic monitoring has been done at two levels that has consisted of updating the [Natural Heritage Information System](#) (NHIS) database with more accurate locational information using GPS technology and a census count of the individuals found at a given location each year. This information has been critical in guiding conservation actions of the species, be it habitat management or environmental review projects.

Demographic monitoring has been directed toward the western prairie fringed orchid and prairie bush clover. This monitoring is more substantive and involves returning to marked plots on the landscape and tracking individual plants from year to year as well as any new recruits that establish within the transect.

In the case of western prairie fringed orchids, we have pursued an even more intensive phenological monitoring protocol. Under this monitoring, individuals are marked multiple times within the same year to document their emergence, growth, capsule development and seed dehiscence. This combination of nested monitoring has led to the

publication of several peer-reviewed papers (Biederman et al., 2018) as well as habitat management guidelines that assist land managers in making decisions that further enhance the conservation of these species.

The western prairie fringed orchid is found throughout the prairie region of Minnesota. Despite this wide geographic distribution, the DNR revisits and completes a flowering census of approximately 80% of the state's populations each season. This effort is only possible because of a collaborative effort between the DNR, The Nature Conservancy, The U.S. Fish and Wildlife Service and the National Park Service. This collaborative partnership also means that information about the species life history and management needs are shared across the entities responsible for the conservation of this rare prairie orchid.

Habitat and Community Monitoring

In addition to species-level surveillance monitoring, the DNR and its partners are actively engaged in ongoing and planned efforts focused on habitats in Minnesota. Habitats consist of the natural environment in which a species lives, grows and reproduces and provides essential resources like food, shelter and breeding sites. It includes all the biotic (living) and abiotic (non-living) factors that influence a species' survival, such as soil type, climate, vegetation and water availability. These factors come together to support the ecological niche for each species, which range from general to very specific. Collections of interacting species that live in the same habitat at the same time are considered ecological communities (e.g., calcareous fens and vernal pools). Not only is it important to understand status and trends of species and their habitats, but also the dynamics of how species interact as communities within habitats through processes such as predation, competition, parasitism and mutualism. The form and structuring of these kinds of interactions vary in spatial scale and shape the broader structure of ecosystems. The exact composition and diversity of a community depends on many factors such as landscape geography, resource availability, disturbance, species interactions and climate. Examples of habitat-level surveillance monitoring efforts in Minnesota led by the DNR and its partners include:

- [Prairie Status and Trend Monitoring Project](#) (SPICE: Sustaining Prairies in a Changing Environment) (DNR; see Case Study)
- [Ecological Monitoring Network](#) (DNR; see Case Study)
- [Forest Health Index](#) (DNR)
- [Wetland Status and Trend Monitoring Program](#) (DNR)
- [Minnesota Wetland Hydrology Network](#) (WHyN; DNR)
- [Stream Index of Biological Integrity \(IBI\)](#)

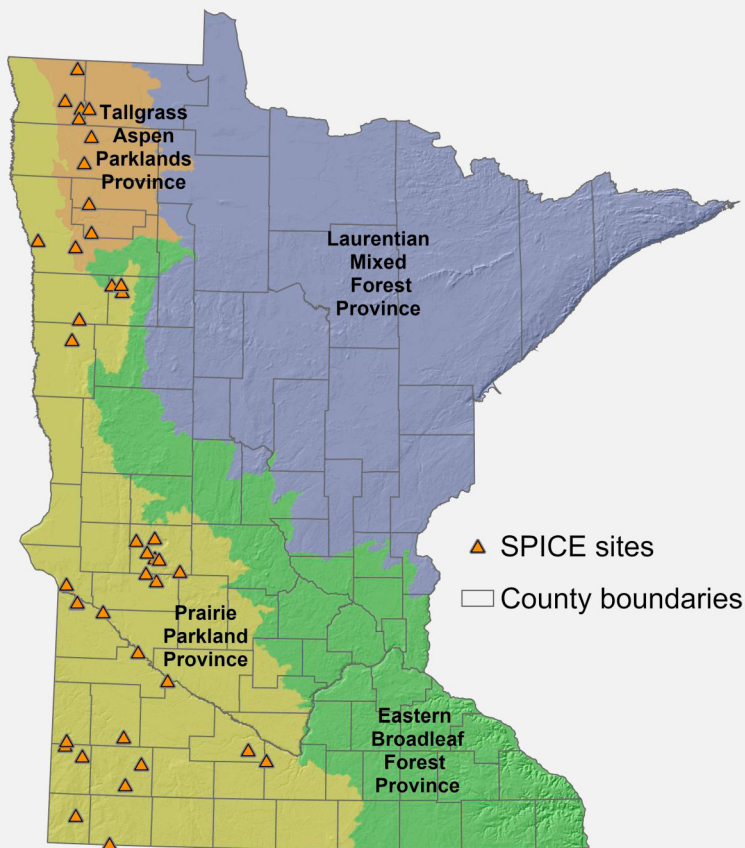
[Monitoring Program](#) (MNPCA)

- [Lake IBI Monitoring Program](#) (DNR)
- [Minnesota Native Plant Community monitoring by relevé sampling](#) (DNR)
- [High Conservation Value Forest Monitoring](#) (DNR)
- [Watershed Health Assessment Framework](#) (DNR)
- [Prairie Reconstruction Initiative](#) (USFWS, USGS, DNR, and TNC)

Case Study: Prairie Status and Trend Monitoring Project

The Sustaining Prairies in a Changing Environment (SPICE) project, led by the Minnesota Department of Natural Resources (DNR), monitors grassland structure, management, plants, birds and pollinators across 40 high-quality prairies in western Minnesota (Figure 5.6). SPICE began after the 2005 State Wildlife Action Plan identified that the highest percentage of Species in Greatest Conservation Need utilized grassland habitats, but little was known about the trends of prairie plant community condition and associated prairie SGCN populations. In 2008, SPICE was designed to evaluate long-term plant and bird community and species trends in context of two primary stressors influencing our remaining native prairies: climate change and landscape fragmentation. A pilot pollinator monitoring effort was added in 2021 and is still being tested and refined.

To address climate change, 40 sites were stratified into five geographic zones spanning a north to south latitudinal gradient across the prairie ecological provinces in western Minnesota – the Tallgrass Aspen Parklands and the Prairie Parklands (Fig. 1). To address fragmentation, sites were selected to meet the following two categories: 1) “Large-embedded” sites are greater than 20 hectares (50 acres) in size having more than 50 percent grassland within 1 km of the site boundary, and 2) “Small-isolated” sites are less than 12 hectares (30 acres) in size having less than 20% grassland within a 1 km buffer.



SPICE also partners with the Grassland Monitoring Team (GMT) – a collaborative comprised of The Nature Conservancy (TNC), the U.S. Fish and Wildlife Service (USFWS), South Dakota Dept. of Natural Resources, and the DNR divisions of Parks and Trails, Fish and Wildlife and Ecological Resources to practice adaptive management utilizing standardized vegetation monitoring protocol data and management information to inform a state-transition model that provides future management recommendations ([Grassland Monitoring Team](#)). In addition to the annual GMT management recommendations, the stratified climate and landscape design from SPICE, large span of monitoring years, and significant GMT partner involvement across many sites has informed the adaptive management process and vegetation response to management (Alhering, 2020), invasive plant species response to climate variables (Ratcliffe, 2022; Ratcliffe, 2024), and trends in bird occupancy and abundance (in prep., see Fig. 2.4). SPICE exemplifies the importance of long-term, multi-objective and multi-partner monitoring efforts to guide effective conservation.

Figure 5.1. Distribution of 40 monitoring sites of high-quality remnant prairie scattered across western Minnesota that make up the Sustaining Prairies in a Changing Environment (SPICE) project led by the DNR. See the [Ecological Classification System](#) (ECS) for province descriptions.

Conservation Effectiveness

To evaluate whether conservation efforts are achieving their goals, effectiveness monitoring serves as a critical tool. It is a form of applied or experimental research, focused on evaluating the effect of targeted conservation actions on ecosystem attributes. This type of monitoring is essential for determining the effectiveness of management interventions such as habitat restoration, invasive species control or policy implementation, in producing desired ecological responses. Grounded in the principles of adaptive management, effectiveness monitoring enables agencies to test specific management hypotheses or learning objectives, which can then be refined based on real-world data. By systematically measuring the success of interventions, it helps identify which actions are yielding positive results and which need modification to improve outcomes for species and habitats. For example, if a restoration project intended

to improve nesting success for a bird species fails to meet its objectives, effectiveness monitoring can guide refinements, such as altering vegetation structure or implementing predator control. Ultimately, this approach allows natural resource managers to respond adaptively to dynamic conditions, including climate change and human-induced habitat changes, ensuring that conservation strategies remain effective and evidence-based.

Structured decision making (SDM), from the field of decision analysis, intends to decompose natural resource problems into a structured sequence, while accounting for underlying values of all stakeholders (Runge & Bean, 2020). A common form utilizes the ProACT cycle to lay out the decision framework, which structures the issue into problem framing, objectives, alternative actions, consequences and evaluation of trade-offs among alternatives that will lead to choosing a preferred alternative action (Figure 5.2).

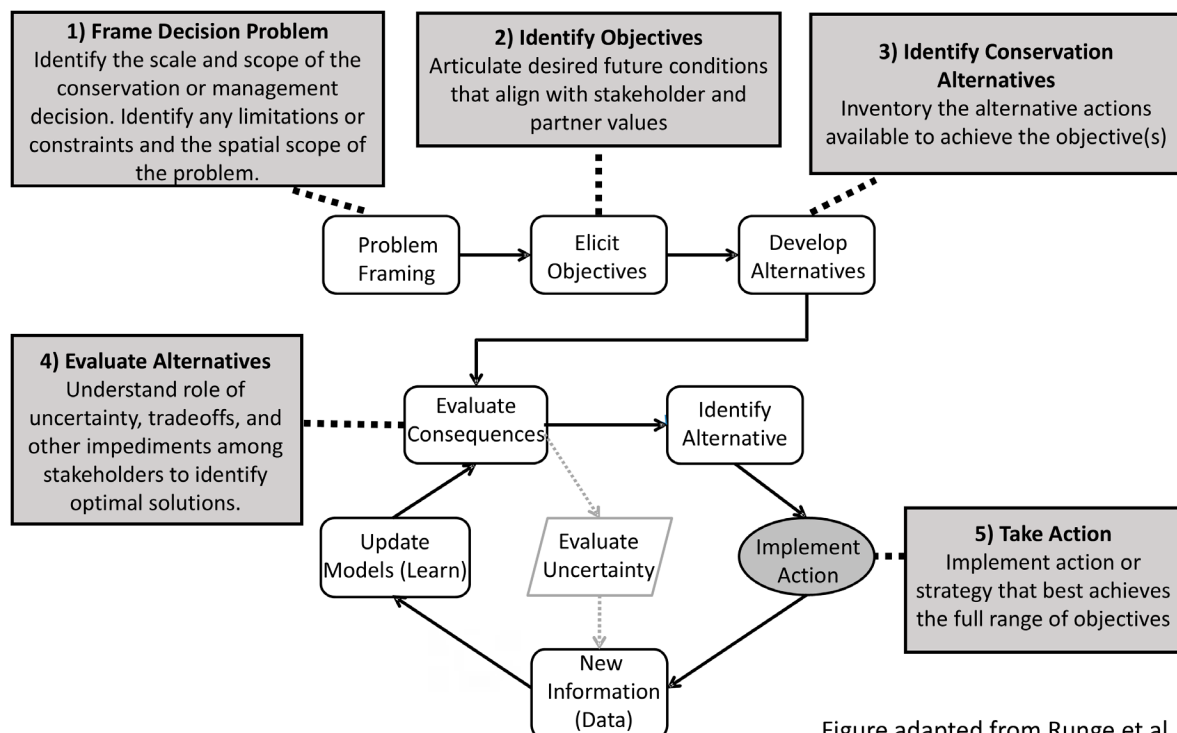


Figure adapted from Runge et al. 2011

Figure 5.2. Diagram of the standard iterative steps involved with structured decision making, of which adaptive management is a sub-discipline. The figure presents a generalized form of the ProACT cycle: Problem, Objectives, Alternatives, Consequences and Tradeoffs.

Adaptive management is a sub-discipline of structured decision making that offers a science-based, iterative approach to decision-making under uncertainty. It emphasizes the use of multiple working hypotheses, coupled with the collection of new data, to update the likelihood of outcomes predicted by those hypotheses (Williams, 2011a). Through repeated cycles of data collection and analysis, the approach seeks to identify the model, represented in each hypothesis, that best describes system dynamics (Figure 5.3).

The process, like structured decision making, involves two fluid and iterative stages: a deliberative phase and an iterative phase. In the deliberative phase, stakeholders collaboratively frame the problem, articulate objectives, identify potential management actions, predict the consequences of those actions, and design appropriate standardized monitoring protocols (Williams & Brown, 2014). In the iterative phase, monitoring data are collected and used to evaluate management effectiveness and inform

the relative support for competing hypotheses. This process of confronting hypotheses with data enables technical learning about ecological systems.

Importantly, adaptive management also facilitates institutional or “double-loop” learning, wherein stakeholders can revisit and revise objectives, actions, or assumptions based on new insights (Argyris & Schön, 1978). Adaptive management can be conducted in either an active or passive form. Active adaptive management emphasizes learning about system dynamics as a primary goal, while passive adaptive management focuses on achieving specific management objectives, with learning considered a secondary benefit (Williams, 2011b). Regardless of the form, effective monitoring and iterative data collection compared against working hypotheses of system dynamics are central to the adaptive management cycle, allowing project refinement and evolving understanding.

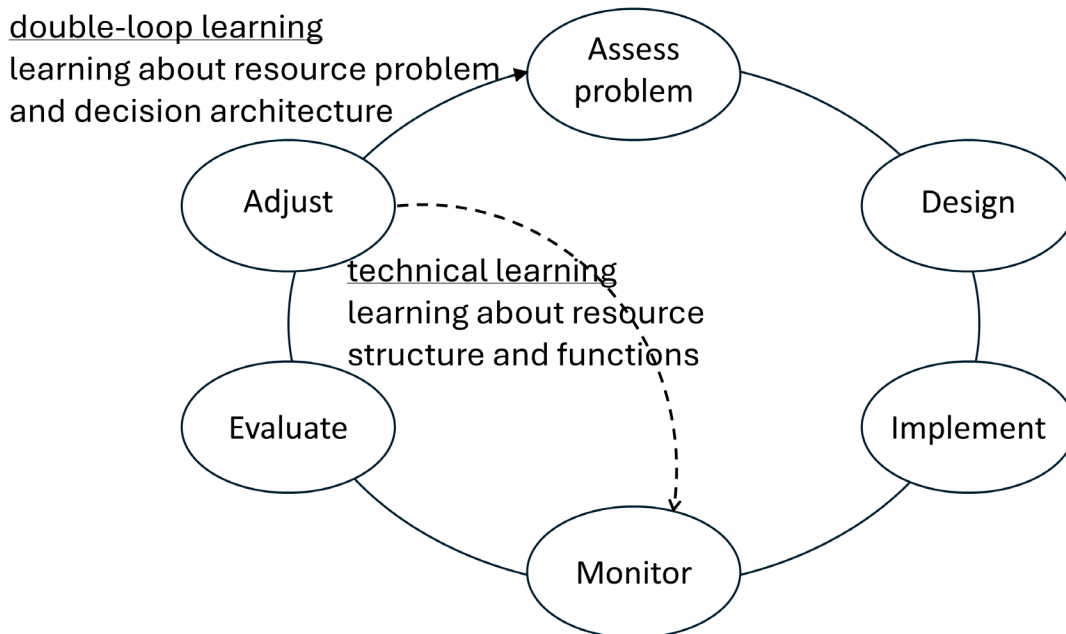


Figure 5.3. Diagram of the standard iterative steps involved with adaptive management, a sub-discipline of structured decision making. The figure presents the generalized form along with opportunities for technical and institutional learning, adapted from (Williams & Brown, 2014).

A prime example of adaptive management in action is the Grassland Monitoring Team (GMT; [Grassland Monitoring Team](#)), a collaboration among the DNR, the U.S. Fish & Wildlife Service and The Nature Conservancy. Formed in 2007, the GMT aims to improve management of native prairies in Minnesota using standardized monitoring protocols embedded within an adaptive management framework and represents a model for collaborative, evidence-based conservation across the state.

The DNR and its partners are actively engaged in current and planned efforts focused on conservation effectiveness monitoring designed with adaptive management in mind including:

- Response of American goshawks to timber management (DNR)
- Response of wood turtles to nest protection and nest site restoration (DNR)
- Response of four-toed salamanders (*Hemidactylium scutatum*) to forest management (DNR; See [Case Study: Four-toed Salamanders and Forest Management](#) in Vernal Pools Subchapter of Chapter 2)
- Evaluating techniques for controlling Smooth Brome in native Prairie (DNR)
- Response of red-shouldered hawks to timber management (DNR)
- Evaluation of management alternatives on bluff prairie habitat (TNC)
- Targeted control of the non-native invasive common reed (*Phragmites australis subsp. australis*) (DNR)
- Patch-burn grazing projects at Chippewa Prairie & Hole in Mountain Wildlife Management Area (DNR)
- Prairie reconstructions in the Prairie Coteau Conservation Opportunity Area and monitoring of birds, butterflies, and bumble bees (DNR)

- Conservation grazing at Hole-in-Mountain Wildlife Management Area (DNR, The Nature Conservancy, Sustainable Farming Association, private cattle producer; See Case Study on Conservation Grazing)
- Prairie reconstruction supplementation with early season forbs for pollinator communities (DNR)
- Bat artificial roost project (DNR; see [Guide to Artificial Roosts for Bats](#))

Estimating Effects from Stressors

Gaining a better understanding of conservation stressors and their effects on species, habitats and communities across Minnesota is an important topic for the next 10-year cycle of the SWAP. When updating our SGCN list by following the NatureServe species conservation status assessment (S-rank process; see Chapter 2: Species in Greatest Conservation Need), we found that the threats assessment component was the most challenging (Salafsky et al., 2008; Master et al., 2012; Keith et al., 2013; IUCN, 2023). Note that we have used the term “stressor” more in this Plan but that we use “threat” here to reference the NatureServe process. The conservation assessment process scores threats according to scope and severity, both measured on an ordinal scale. Scope measures how widespread a threat is in space, while severity describes how damaging a threat is to the affected portion of the population. Geographic Information System (GIS) layers representing area of species occupancy (via distribution maps, known occurrences, and modelled habitat) intersected with spatial information about where in space a given threat occurs can be used to represent scope, but such information is limited and future trends difficult to predict requiring more investment for accurate spatial representation of threats. Severity relates to how much a SGCN population is expected to decrease over some time frame (e.g., 10 years) as a result of exposure to a particular level of a specific threat. Data to inform these estimates are

very hard to find and estimates by experts and ecological analogs (effect data from similar species in similar systems) are integrated into the assessment. We emphasize the need to better understand the interactions between threats and species effects in the next 10-year SWAP cycle, not only to improve conservation

status assessments, but also to help identify actions that will have the greatest impact. The area of need described here falls under the umbrella of experimental or mechanistic research, which requires well-designed studies around clear and focused questions.

Case Study: Conservation Grazing at Hole-in-the-Mountain Prairie

In 2018, the DNR in partnership with The Nature Conservancy, U.S. Fish and Wildlife Service, The Sustainable Farming Association and a local producer launched a long-term monitoring project on a 566-acre parcel of remnant prairie at the Hole-in-the-Mountain Wildlife Management Area (WMA) to study how vegetation structure and species composition respond to a patch-burn cattle grazing approach. The project was expanded in 2021 to include evaluating a response to adaptive management grazing. The objective was to evaluate whether innovative grazing techniques can increase structural heterogeneity and species diversity in a prairie invaded by smooth brome, an invasive grass. A central aim is to improve wildlife habitat through cooperation with a local cattle operation. This project can help enhance habitat on private working lands, which is critical for slowing or reversing wildlife population declines in prairie region ecosystems. Vegetation data show that grazing is increasing overall plant species richness of both native and non-native species.

Because prairie ecosystems include more than plants, this project has evolved into an interdisciplinary monitoring approach. The DNR Nongame Wildlife Program and Minnesota Biological Survey are also monitoring responses of grassland-obligate birds, bumble bees and butterflies including several Species in Greatest Conservation Need (SGCN). Most SGCN birds show no negative effects from grazing, except bobolinks, which appear sensitive to the shorter grass structure. Some species, like the western meadowlark, are declining at both the treatment and nearby control sites —mirroring broader regional trends and suggesting no evidence of a positive grazing effect. The DNR initiated monitoring for bumble bees and butterflies in 2023.

We anticipate future data will offer clearer insights into how prairie specialist SGCN respond to these grazing techniques. Past low management grazing and subsequent lack of disturbance at the site led to smooth brome invasion and altered soil conditions, which will take time to address. This project underscores the importance of managing for resilience amid increasing variability in precipitation. Diversity and connectivity across space and time is the foundation of that resilience, and these grazing techniques may offer a viable and economically sound approach to restore prairie ecosystems.



Photo: Hole-in-the-Mountain prairie, Lisa Gelvin-Innvaer

Best Practices for Survey, Monitoring, and Research Design

Resource management agencies, such as the DNR, work with two categories of ecological data: (1) data already collected and (2) data to be collected in the future. In this section we address best practices for utilizing and applying existing datasets to future conservation applications as well as how new data collection can be strategically designed to address emerging management needs and fill knowledge gaps.

Existing ecological data from past surveys, monitoring programs, and research efforts can provide critical insights for conservation planning and adaptive management. Such data have been shown to inform targeted habitat protection and protected area designation (Guisan et al., 2013; Bennett et al., 2018), support cross-scale data integration for invasive species management (Xie et al., 2022), enable integrated models for abundance, survival, and occupancy estimation (Sun et al., 2019; Doser et al., 2022) and help redefine key biodiversity metrics such as extent of occurrence, area of occupancy, and population trends (Bosso et al., 2024; Gallagher et al., 2025). In Minnesota, existing datasets have played pivotal roles in conservation decisions. For instance, when bat populations across North America began suffering from white-nose syndrome, a deadly fungal pathogen, DNR's survey and monitoring data were instrumental in informing the U.S. Fish & Wildlife Service during its deliberations to federally list several bat species.

The DNR relies heavily on living data repositories such as the [Minnesota Natural Heritage Information System \(NHIS\)](#), which is continuously updated and standardized as new information becomes available. NHIS is the state's most comprehensive source on rare plants, animals, native plant communities, and other significant natural features. It provides rapid, authoritative insights to guide conservation priorities and project reviews. Complementing NHIS, the [Minnesota Conservation Explorer](#) makes Natural Heritage

Data more accessible by allowing authorized users to explore natural resource data, generate maps for conservation planning, and request Natural Heritage Reviews to evaluate potential project impacts on rare species and sensitive resources.

NHIS data directly inform conservation action. NHIS records help determine whether a protected species is likely to occur in a proposed project area and, if a take permit is requested, assess the potential statewide significance of that impact. They also guide proactive conservation strategies such as land protection, habitat management for threatened and endangered species, and species translocation to suitable habitats. For example, when development projects affect waterways, NHIS data are used to evaluate whether aquatic mussels should be relocated out of harm's way.

In the sections that follow, we present two complementary areas of focus. The first addresses best practices for handling, managing, and curating existing ecological data, recognizing both the value and limitations of previously collected information. The second outlines key design elements and statistical considerations for the collection of new ecological data, emphasizing actions and strategies that enhance data quality, comparability, and long-term utility for conservation decision-making. The principles to be applied retrospectively for existing data are also important to consider ahead of time prior to collecting new ecological data.

Principles for Effective Use of Existing Data

Survey, monitoring, and research efforts are only as useful as the quality, accessibility, and interpretability of the data collected. Well-managed data ensure that years of field effort yield lasting value, providing information that remains usable for decision-making and future analyses (Michener & Jones, 2012). With intentional and consistent data management practices, datasets can be preserved in complete, well-documented, and accessible forms, maximizing their long-term impact and utility (Binley et al., 2024). Recognizing data as a core scientific product — rather than a secondary byproduct of fieldwork — ensures that the DNR will deliver long-term value for both ecological research and applied conservation.

Comprehensive metadata is the backbone of reusable and interpretable datasets. Regardless of whether efforts were aimed at surveys, monitoring, or research, at a minimum, metadata should answer the basic questions of why, who, what, where, when, and how (Michener, 2006). For ecological data, this extends beyond objectives and methods to include observer training levels, equipment calibration, and known limitations of inference. Existing datasets must also account for potential sources of bias such as nonrandom sampling, preferential selection of higher-quality habitats, observer differences, or uneven survey effort across space and time. Such biases can limit the generalizability of results and constrain how data can be applied to broader conservation questions. Accordingly, datasets should be explicitly evaluated for representativeness, and any spatial, temporal, or methodological biases clearly documented to guide appropriate use and interpretation.

Metadata should adhere to clear or accepted standards, such as the [Ecological Metadata Language \(EML\)](#), and be stored alongside the data to facilitate long-term reuse (Fegraus et al., 2005). Historical or opportunistic datasets

often lack this level of documentation, yet they may still be valuable if limitations are clearly articulated. When documentation is lacking, institutional knowledge becomes vital. Interviews with long-serving staff members can help fill in gaps, recover lost metadata and provide critical context.

Clear assignment of roles and responsibilities is essential for successful ecological data management. Effective projects designate not only data collectors, but also managers, curators, and end users who each play a part in ensuring data quality and accessibility (Reichman et al., 2011). Field staff and observers are responsible for accurate collection and recording, data managers and curators ensure standardization and documentation, and analysts and decision-makers interpret outputs in the context of conservation objectives. Establishing expectations for each of these roles fosters accountability and minimizes errors, ensuring data integrity throughout the project lifecycle.

Evaluating past datasets and developing future datasets in the context of robust quality control protocols helps to identify their strengths and weaknesses vital to ensuring subsequent application is accurate and reliable. Workflows should include error detection and correction steps such as cross-checking field entries, applying range checks, and using automated validation routines. For example, range rules can flag impossible values (e.g., out-of-range coordinates, dates, or biologically implausible measurements), while duplicate checks can identify repeated records (Yenni et al., 2019). Validation processes not only increase confidence in the data but also reduce the risk of propagating errors into downstream analyses or management decisions.

Survey, monitoring, and research activities generate diverse forms of data, ranging from tabular counts and environmental covariates to photographs, audio recordings, video, and geospatial (GIS) files. Each data type requires tailored management strategies. For example, image and acoustic data need metadata

describing collection equipment, settings, and conditions; geospatial datasets require attention to coordinate systems and accuracy; and tabular data require standardized variable names and units (Kelling et al., 2009). Treating each data type according to best practices ensures that datasets remain interpretable and integrable into broader ecological analyses. To the extent possible, standardization and integration ensure that data from different sources can be aligned to a common format, taxonomy, measurement unit, and coordinate system. Combining related datasets — for example, surveys for Dakota skippers (*Hesperia dacotae*) from different years and parts of Minnesota — can greatly enhance analytical utility.

Durable archiving is essential for survey and monitoring datasets that may be needed years or decades into the future. Data should not be stored only on local computers, where the risk of loss is high, but instead deposited in secure repositories with established backup systems and long-term curation support (Costello et al., 2013). This applies not only to large, high-profile monitoring programs but also to smaller-scale or project-specific datasets, which often contain valuable, fine-grained information that can be critical for future analyses, baseline comparisons, or integration with broader datasets. Such localized or narrowly focused data are particularly vulnerable to being overlooked or lost if not intentionally archived. For Minnesota, durable storage solutions include centralized systems such as the NHIS, which provides ongoing curation and accessibility for a wide range of biodiversity data.

Data management should be explicitly tied to the anticipated uses of survey and monitoring datasets, such as population trend analysis, habitat prioritization, or conservation planning. Designing management protocols with these goals in mind ensures that data remain fit for purpose and compatible with future datasets (Lindenmayer & Likens, 2010). Integration across time is especially important and projects should establish mechanisms to link existing

data with new collections, facilitating long-term analyses that are critical for detecting ecological change. This forward-looking approach enhances the utility of monitoring programs and ensures that ecological data continue to inform conservation and management well beyond the life of the original project.

Modern integrated analyses increasingly rely on combining multiple datasets collected across different times, places, and projects to address shared ecological questions (Pacifi et al., 2017; Zipkin et al., 2021). While such integration can greatly enhance the scope and power of long-term monitoring, it requires careful attention to whether datasets are truly compatible. Differences in survey design, sampling effort, observer training, detection methods, and spatial or temporal coverage can introduce biases if not properly accounted for. For long-term monitoring projects in particular, where subtle changes in populations or habitats are being tracked, even small methodological inconsistencies can compromise inference. Rigorous evaluation of metadata, documentation, and data quality is therefore essential before integrating disparate datasets, ensuring that combined analyses provide meaningful and defensible insights for conservation and management.

Despite its importance, ecological data management is frequently underappreciated and underfunded. Too often, budgets prioritize field collection while neglecting data curation, archiving, and accessibility (Michener & Jones, 2012). To ensure long-term value, projects must treat data as a primary deliverable — on equal footing with reports or peer-reviewed publications — rather than a secondary output. This requires allocating resources for trained personnel, infrastructure, and ongoing stewardship. By embedding data management into project planning and funding from the outset, the DNR can safeguard the integrity and future utility of their ecological datasets.

Principles for Effective Study Design and Collection of New Data

The following sections provide an overview of key statistical and experimental design principles to consider when developing a new project aligned within the scope of the SWAP, prior to collecting data. Whether for surveys, monitoring or research, designing an ecological study requires careful consideration of the specific goals, objectives, spatial and temporal scales, methodological approaches and logistical constraints of a given project, ensuring that the data collected are both valid and informative for the question(s) at hand. The subject is explored in depth across numerous textbooks and peer-reviewed publications, reflecting the nuanced challenges of capturing and understanding ecological patterns and processes reliably. While not exhaustive, we provide citations below to excellent resources that expand upon the ideas presented here.

Defining Objectives

The overarching goal of SWAP-related projects is to generate data that will provide useful information about ecological system states, population trends, effectiveness of conservation actions or negative effects from stressors. To reach any of these goals requires clearly defining the objectives and question(s) and articulating precisely what metrics are to be measured or tested and why. In the context of the SWAP, the study's objectives must align with broader management or conservation goals. To be effective, objectives should be specific, defining the purpose, scope and responsible parties; measurable, by including clear metrics for evaluating ecological responses; achievable, considering time, personnel and logistical constraints; relevant, in that they address current conservation needs or priorities; and timely, with explicit benchmarks and timelines to guide implementation and assessment (Doran, 1981; but see Bjerke & Renger, 2017).



Photo: Biologist recording data in the field

Defining the Target Population

An essential element of a good study design is the definition of a relevant target population and a corresponding sampling frame. The target population refers to the ecological entities or areas to which inferences will be made — such as a species across its known range or specific ecosystems like Bluff prairies in the Driftless region of Minnesota. The sampling frame, in turn, is the set of all possible units (e.g., geographic locations with a species' range, or individuals within a larger animal population) that could potentially be sampled. It is crucial that the sampling frame is explicitly defined, comprehensive and accessible, as it directly determines the validity of any statistical inference. Valuable tools for defining target populations and sampling frames spatially are GIS systems such as ArcGIS and QGIS, which are used to integrate and analyze remote sensing data from Earth-observing satellites (Landsat); Moderate Resolution Imaging Spectroradiometers (MODIS); laser imaging, detection, and ranging sensors (LiDAR); and drone imagery. A poorly defined frame increases the risk of producing biased or unrepresentative results, thereby reducing their value for informing decision-making. Sound experimental design, rooted in these principles, ensures that data collected in the field are robust, reproducible and directly informative for science-based resource management.

Probability-based Sampling

Another critical principle is to use a probability-based sampling design for collecting data in a way that supports unbiased statistical inference by selecting sampling units that represent larger populations (Thompson, 1992). Simple random sampling is the most basic approach, where every sampling unit in the study area has an equal probability of being selected. It is easy to implement, but can lead to uneven spatial coverage, sometimes resulting in clustered sampling locations with gaps in landscape representation. This is more likely to occur in ecological studies examining patterns across space.

To account for this reality, stratified random sampling improves upon the design by dividing the study area into distinct groups or strata based on characteristics like habitat type, geographic zone or elevation. Random samples are taken within each stratum helping to ensure that important groups are represented in the sample. This increases the precision of estimates, particularly when strata are distinct, but it does not guarantee that sampling units will be evenly spaced across the landscape.

Generalized Random Tessellation Stratified (GRTS) sampling goes further by combining the value of random sampling with a spatial balancing mechanism (Stevens & Olson, 2004). It is a form of probability-based sampling within the broader framework of sampling designs where each spatial unit has a known non-zero probability of being selected. It can accommodate unequal inclusion probabilities, stratification and hierarchical designs that reduce clustering of samples by spreading them evenly across the spatial scope of inference. It is particularly useful for broad-scale environmental monitoring, where consistent coverage of diverse landscapes is important. GRTS supports flexible designs including rotating panels for long-term trend detection. The spatial balance and design flexibility make this design particularly useful for ecological applications.

In some situations, randomization may not be feasible due to logistical constraints and study areas covering large geographic expanses; in these cases, systematic sampling where samples are placed at regular intervals — can be a suitable alternative. However, care must be taken to confirm that there are no hidden spatial or temporal patterns in the sampling frame that could introduce bias into the results.

Sampling Unit Replication

Replication is another cornerstone of effective study design. Including multiple independent sampling units, such as plots or sites, allows researchers to accurately estimate variability and capture the natural heterogeneity of a target population. Replication also strengthens

the statistical power of a study, increasing confidence in detecting real patterns or treatment effects.

Randomization

Randomization is another key design principle that strengthens the validity of field studies. By randomly assigning management treatments and controls among experimental units — such as grazed versus ungrazed plots — one can avoid confounding effects and help ensure that observed differences in outcomes are attributable to the treatment itself rather than other uncontrolled variables. This approach enhances the internal validity of a study and supports stronger causal inference. Even in basic research applications that do not warrant control plots, randomization of sampling plots among strata within the sampling frame is essential for unbiased estimation of occupancy, abundance or relative abundance.

Statistical Power

Prior to collection of any new data, it is important to ensure that studies are designed with sufficient sample sizes and statistical power to detect biologically meaningful effects. Also, without enough replication (and beware of pseudo-replication; Hurlbert, 1984), even well-designed studies may fail to identify important patterns or changes due to high variability or low signal-to-noise ratio. Conducting pilot studies or using simulations can help inform the number of samples needed to achieve acceptable power for detecting ecologically relevant effect sizes; prospective power analysis is key (Steidl et al., 1997). This planning step is particularly important when resources are limited, as it helps prioritize efforts and ensure that results will be informative for decision-making.

Incorporating Controls

Equally important is the inclusion of controls units — areas or plots where no treatment or management action has occurred — which serve as a baseline for comparison. This is especially critical when

evaluating the outcomes of conservation interventions or disturbances. Designs such as Before-After-Control-Impact (BACI) are particularly powerful in assessing the effects of management actions, as they compare changes over time at both treatment and control sites, helping to isolate the true impact of the intervention from natural background variability (Green, 1979).

Temporal and Spatial Designs

A thoughtful temporal and spatial design are also important, especially in ecological studies where environmental conditions in the field can fluctuate substantially over time and space. Incorporating repeated observations through time — whether seasonal, annual or over multiple years — allows researchers to capture trends, identify cyclical patterns and reduce the effect of short-term variability that may obscure true ecological responses. In the analysis phase, it is ideal to account for temporal autocorrelation, where observations collected closer together in time are more similar than those further apart. Ignoring this structure can lead to underestimated uncertainty and overconfidence in conclusions.

Similarly, the spatial design must be carefully planned to ensure that landscape heterogeneity is properly represented. GIS and remote sensing data are readily available to help define and stratify heterogeneous landscapes. The spatial distribution of sampling locations should reflect the spatial scale at which the focal species, ecological system or key processes operate, such as home range, habitat extent or the geographic scope of ecological dynamics. For instance, heterogeneous habitats require spatial sampling that captures variability within and across patches. Stratified random sampling across different habitat types, elevation zones, or land-use categories can improve inference and help ensure that results are generalized beyond the sampled sites. Moreover, spatial autocorrelation — where nearby sites tend to have more similar conditions or species assemblages than distant ones — should be considered both in study design and in

statistical modeling. Failing to do so may inflate the apparent sample size and lead to spurious findings. Together, thoughtful temporal and spatial designs are essential for robust ecological inference. They increase the reliability of estimates, improve the ability to detect meaningful changes or relationships and provide critical context for understanding the dynamics of complex natural systems.

Animal and Plant Detections

Observations of animals and plants in nature rarely reflect true population dynamics because of detection and measurement error, which can significantly bias results if unaccounted for. Many ecological field studies face challenges with imperfect detection — failing to observe a species or event when it is present. To mitigate this, personnel should design sampling protocols that incorporate methods to estimate and correct for detection probability (Otis et al., 1978). These may include repeated surveys at the same site to estimate occupancy, distance sampling to model detectability as a function of distance from the observer, time-to-detection methods, double-observer approaches or mark-recapture techniques (Williams et al., 2002). When it is not feasible to directly estimate detection probability, models should include covariates that influence detection (such as time of day, weather, or observer experience) to control for this variability implicitly. By integrating these strategies, field studies can produce more accurate and reliable inferences about the true ecological processes that are driving observed patterns.

Emerging technologies are also transforming wildlife survey methods by offering powerful tools to augment traditional survey and monitoring approaches, helping biologists and researchers detect animals more efficiently, across broader spatial and temporal scales, and with reduced bias. Tools such as environmental DNA (eDNA), Adapted-Hunt Drift Fence Technique (AHDriFT), and automated acoustic monitoring are increasingly being adopted or



Photo: DNR biologist conducting a broadcast survey for red-shouldered hawks, Amy Westmark

studied for their potential to improve species detection and monitoring outcomes, particularly for elusive, rare or low-density species (Lugg et al., 2018).

Technologies like eDNA allows researchers to detect species by collecting and analyzing DNA that organisms shed into the environment (e.g., water, soil, snow). This method can be highly sensitive and is particularly useful for detecting aquatic or cryptic terrestrial species without the need for direct observation or capture (Goldberg et al., 2015; Rees et al., 2014; Davis et al., 2025). Likewise, AHDriFT combines low-profile drift fences with motion-triggered cameras to document small-bodied amphibians, reptiles and mammals, offering a passive and non-invasive approach to detecting ground-dwelling species (Martin et al., 2017;

Amber et al., 2021). Of particular utility are automated acoustic monitoring systems that use programmable audio recorders to capture vocalizations such as bird songs, frog calls or bat echolocation. These recordings can be analyzed using software or expert review and have proven useful for long-term, broad-scale surveys (Sugai et al., 2019). When used in concert with conventional methods, these technologies enhance detection probability, reduce effort and observer bias and help fill key ecological knowledge gaps needed for informed conservation decisions.

Standardized Protocols

Establishing clear and consistent data collection protocols is fundamental to ensuring data quality and enhancing the value of field studies. Standardized protocols — especially those aligned with nationally or regionally recognized methods — promote consistency in how data is collected, making it easier to compare results across studies, contribute to broader ecological databases and support meta-analyses. Calibration of equipment, consistent training for field staff, and detailed documentation of procedures all contribute to the reliability and reproducibility of findings. When protocols are widely adopted, they also support data integration efforts that can increase statistical power and expand the scope of ecological inference.

Estimating and Communicating Uncertainty

Inferential uncertainty can arise from various sources in ecological modeling and parameter estimation, including natural variability in the underlying process(es) at work, data limitations and structural assumptions in models. Explaining the nature, sources and implications of uncertainty can be especially difficult when communicating with decision-makers, landowners or the general public. Point estimates alone can be misleading if not accompanied by measures that convey the range of plausible values, such as confidence intervals (in frequentist approaches) or credible intervals (in Bayesian frameworks). It is also essential to acknowledge and

describe the sources of uncertainty in a project or study, which may include sampling error, measurement error and model-based uncertainty.

Communicating scientific and model-based uncertainty is challenging, particularly when engaging with audiences unfamiliar with the concept. Many stakeholders are accustomed to receiving definitive answers rather than probabilistic information. For example, people frequently encounter weather forecasts that express uncertainty, such as a 40% chance of rain, but may interpret such predictions in binary terms (either rain will occur or will not), highlighting the cognitive challenge of understanding probabilistic information (Gigerenzer et al., 2005). This tendency can be amplified in policy and natural resource decision-making contexts, where stakeholders may expect clear guidance or action, not ranges or degrees of confidence. Misinterpretations of uncertainty may erode trust in scientific findings or be used to justify inaction (Fischhoff & Davis, 2014). Furthermore, the language used by scientists with terms like “confidence intervals,” “model error,” or “credible intervals” can be opaque or intimidating to non-technical audiences.

Effective communication strategies include using visual aids (e.g., shaded confidence bands or probability distributions), focusing on the implications of uncertainty rather than the technical details, and framing uncertainty as a normal and informative part of the scientific process. Trust is critical; when science communicators are perceived as transparent and credible, stakeholders are more likely to accept and act on uncertain information (McInerney et al., 2014). Transparent communication of uncertainty not only strengthens scientific integrity but also supports sound decision-making by making the limits of inference clear to policymakers, managers and the public.

Use of Statistical Models

A cornerstone of effective field study design is the use of appropriate statistical models to

address questions of interest. Depending on the study question, the type of statistical model will differ. It is suggested that models can fit into one of three applications: exploration, inference or prediction (Tredennick et al., 2021). Arguably the most prevalent use of statistical models is for exploration, where one seeks to describe patterns in the data and generate hypotheses about what drives ecological processes. On the other hand, modeling for inference formalizes sets of alternative hypotheses describing how a system functions or responds, which in turn are evaluated against empirical data. This effort comprises evaluation of model coefficients associated with hypothesized covariates of importance, which can be positive or negative, and have lesser or greater influence relative to other covariates. Modeling for prediction is likely the least utilized function by state natural resource agencies. This type of modeling simply seeks to determine which of some set of models will best predict response values for new observations of essential covariates. The use of models should align with what the work is being conducted for in the first place. Regardless of the purpose for modeling, be mindful to avoid the trap of relying on p-values within a significance testing framework to decide whether and which factors are more important for explaining variation attributable to some factor(s) (Johnson, 1999). Rather, it is good practice to consider effect sizes and biological significance of factors used in models (Johnson, 1999). The forms of these models, the paradigm of statistical thinking and model selection uncertainty are beyond the scope of this brief narrative but suffice it to say that there are many volumes dedicated to this diverse subject (McCullagh & Nelder, 1983; Gelman et al., 1995; Burnham & Anderson, 1998; Hastie et al., 2001).

Adaptive Designs

Finally, an effective ecological study design should be adaptive and iterative, allowing for refinement as new insights emerge. Adaptive monitoring acknowledges that ecological systems are dynamic, and that

initial assumptions or methods may need adjustment over time. By regularly evaluating data as it is collected, researchers can modify sampling designs, protocols or analytical approaches to improve efficiency, address emerging questions, or respond to unexpected challenges. Embedding monitoring within a broader decision framework — such as structured decision making or adaptive management — further enhances its value (Figures 5.1 and 5.2). These frameworks emphasize learning by doing, using monitoring results to inform and update management actions in a continuous feedback loop. This iterative process not only increases the relevance and responsiveness of ecological studies but also ensures that monitoring contributes directly to evidence-based conservation and resource management. Together, all these principles form the foundation of statistically sound, reproducible and management-relevant ecological field studies.

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