Integrated Strategy for Understanding Effectiveness of Monarch Conservation

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Abstract

This plan describes a strategic framework for an integrated approach to monitoring effectiveness of monarch butterfly conservation. Because the size (ha) of overwintering habitat area colony occupied by the core North American monarch butterfly (*Danaus plexippus plexippus*) population has greatly declined since peak coverage during the 1990s, the USFWS and the Monarch Joint Venture have established national and regional initiatives to increase numbers of monarchs and reduce the threat of extinction. The aim of this monitoring strategy is to demonstrate the effectiveness of conservation efforts. Strategically, the monitoring will be designed to: 1) determine the status and trends of the monarch over broad spatial extents and identify factors potentially driving those trends, 2) inform local efforts on the efficiency and effectiveness of habitat restoration efforts, and 3) engage citizens in collecting data and promoting monarch conservation. A key element of this effort is the use of information on the response of monarchs and food resources to localized habitat management to inform and evaluate a broader scale model of population response and viability. Another vital aspect of the effort is to incorporate citizens into the monitoring program. Engaging the public will not only strengthen conservation awareness, it could also allow less-costly collection of data on factors that may influence migration and availability of food resources over a large area. Operationally, an integrated monitoring program will entail a large-scale sampling design and collection of a core set of attributes using existing protocols and data portals whenever appropriate. Employing a large-scale sampling design will help identify locations where core data should be collected and emphasize how partners can best contribute to conservation monitoring.

Problem Statement and Rationale

The monarch butterfly participates in one of the most spectacular migrations in the animal kingdom, migrating across 3,000 km each fall in North America to overwinter in high-altitude fir forests in central Mexico and in forest groves along the Pacific Coast. In spring, monarchs return northward, over the course of two generations to recolonize their breeding range, where they depend on milkweed (*Asclepias* spp.) as a larval host plant. Historically, the greatest perceived threat to the species was deforestation at overwintering sites (Oberhauser et al. 2008, Brower et al. 2012; Ramirez et al. 2015), but attention recently has shifted to loss of milkweed in monarch breeding locations owing to shifts in agricultural practices in the central United States (Pleasants and Oberhauser 2012). As a result, reducing the negative effect of habitat loss has emerged as a top conservation priority to slow, halt, and ideally to reverse population declines. However, over the same approximate period that a decline in overwintering area occupied by monarchs has been observed, other monitored butterfly species around the world have experienced similar patterns of decline. Thus, while changes in milkweed availability undoubtedly affect monarch abundance trends, other large and small-scale factors likely have contributed to declines, including loss of habitat with suitable nectar sources needed during migration, climate variability (Zipkin et al. 2012, Brower et al. 2015, Nail and Oberhauser 2015), diseases (summarized in Altizer and de Roode 2015), and insecticide use (Oberhauser et al. 2006, Oberhauser et al. 2009, Freese and Crouch 2015).

Lack of data from intensive monarch population studies contributes strongly to our inability to accurately attribute cause-effect relationships driving observed declines. However, there are several programs that provide data on butterfly population trends across environmental gradients. One such program has examined the community of butterflies residing along an elevational gradient into the Sierra Nevada Mountains of California. This study, by Casner et al. (2014), saw steep declines for some species, increases for others, but little change for the monarch from 1999 to 2007. Overall, they found disparate responses to weather among the thirty-six species monitored. Similar data exist from the growing network of Butterfly Monitoring Programs (Ries and Oberhauser 2015), many of which are in the heart of the key Midwestern breeding range for monarchs. Increasing the geographic coverage and scope of these programs will be important for this strategy because it will help ensure monitoring data are representative and not leading to conclusions that may not be applicable to unsampled portions of the monarch's range. The National Wildlife Refuge System, along with other public land management agencies, is poised to fill in important spatial gaps to produce more extensive data for modeling population growth and quantifying habitat conditions. Integrating research with collection and analysis of the monitoring data will improve the ability to understand why expected trends or targets are not occurring.

Currently, the main parameter for determining the status and trend of the eastern segment of the population is size (in hectares) of the overwintering monarch butterfly colonies in Mexico (Brower et al. 2012). Currently, this parameter can only be converted to estimates of butterfly population size (i.e., total number of individuals) using the product of two other estimates: the number of butterflies per tree and the number of roost trees per colony. While there is not scientific agreement on the number of butterflies per hectare (e.g. Calvert 2004, Brower et al. 2004), most researchers agree that it is valid to assume that, as the area of the colony expands, so does the population size of butterflies. The number of overwintering butterflies at year t divided by the number during a previous year (t-1) gives one estimate of the annual growth rate (λ) for the population. This estimate of trend in population size since the early 1990s can be used in demographic matrix models and for forecasting population performance and extinction risk in the future (e.g. Semmens et al. in preparation). There are also empirical data from a limited area in the monarch's main breeding range correlating amount of milkweed plants with the subsequent size of the overwintering population in Mexico (Pleasants and Oberhauser 2012), providing good predictive linkages between habitat available in one season and population performance in another (Figure 1).

On a national scale, monitoring of monarchs and their host plants is carried out in several citizen science projects with broad coverage throughout the breeding, migration, and overwintering habitats in the U.S. (summarized in Oberhauser et al. 2009). However, because these projects depend on volunteer-selected monitoring sites, they do not use a systematic spatial sampling scheme. Using such a sampling scheme to incorporate monarch monitoring into federal lands will add to our ability to address key conservation questions such as how much habitat of a given quality is needed to sustain or increase monarch abundance. Other significant unanswered questions relevant to establishing best management practices for the monarch include the degree to which milkweed is a limiting resource for the monarch, how milkweed's role as a limiting resource varies spatially and temporally over large and small geographic scales, whether phenological mismatching (asynchrony between availability of resources such as milkweed and presence of monarchs) contributes to monarch declines, what role weather and climate play in monarch population dynamics, the importance of small geographic scale (ca. 10-100 m) variations in habitat and climate in providing resilience for monarch populations (the ability to maintain monarch abundance in the face of temporal variation in environmental conditions), whether the monarch is entering an extinction vortex in which disease plays a significantly larger role in population decline, and defining the nature of landscape connectivity for the monarch. Determining if and where phenological mismatches occur is critical to supporting modeled scenarios of climate change and to determine how refuge habitat management actions will correspond with monarch use, reproduction, survival and ultimately abundance in a given year.

Therefore, building from existing protocols to establish systematic, long-term and large-scale monitoring of monarchs and milkweed across the United States is essential for understanding monarch population dynamics through space and time. The distribution of public and privately administered lands across the monarch breeding range means that an organized and coordinated effort will be needed to implement this approach that will rely on multiple cooperators. As such, we envision broad application of citizen science for monitoring of key attributes about monarchs and leading factors that likely influence their population processes. For example, milkweed density gathered systematically over the extent of the monarch breeding range can be related to environmental covariates (e.g., land cover, landscape physiognomy, weather and climate, timing of milkweed and monarch life history events) to better understand spatio-temporal relationships among abundance of milkweed and monarch breeding-season and winter population sizes (see Figure 1).

Systematic Monitoring of Species Occurrence and Reproductive Performance

An integrated (research and monitoring) program will be able to document the impact of threats to monarchs, and measure the effectiveness of conservation and management actions taken to mitigate those threats. Because monarchs are wide-ranging and can travel many hundreds of kilometers annually, an effective monitoring program to document changes in their population and distribution must be large in geographic scope (e.g., range-wide, continental). Local land managers also need methods to monitor monarchs on and around their properties to determine the effectiveness of their conservation and management at smaller spatial scales (e.g., wildlife refuge, national park, state forest), while species biological experts need to understand impacts of a fuller range of threats and actions, discoverable through hypothesis driven and more intensive research (Appendix B). Thus, this integrated approach will help coordinate, identify opportunities and provide the information needs for many partners working to conserve the monarch butterfly (Figure 2).

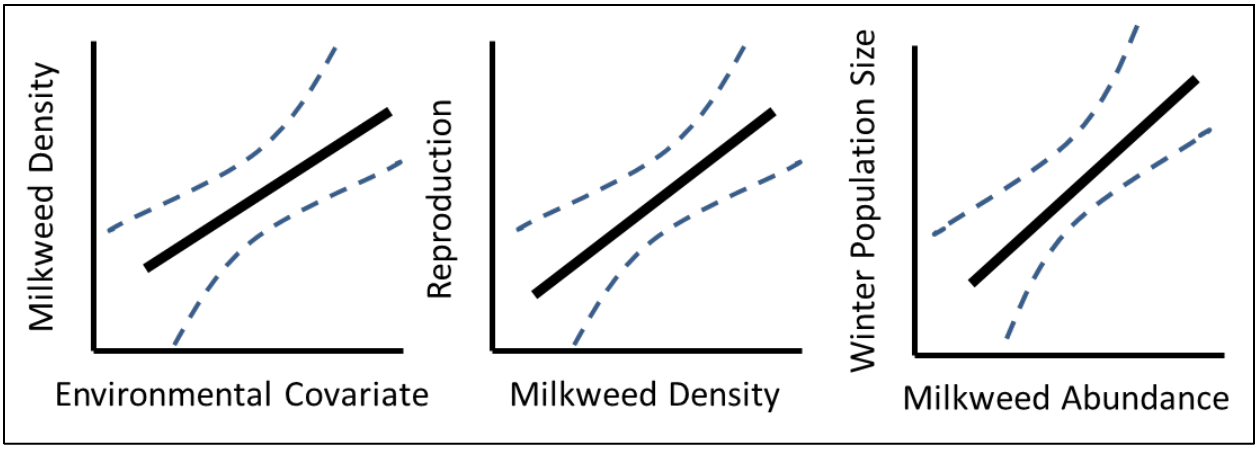

Figure 1. Milkweed density is explained by spatially and temporally varying environmental covariates; milkweed density, in turn, can explain monarch reproduction. Milkweed abundance (density × area occupied) in the breeding ground also explains a large portion of variation in the population size on the wintering grounds.

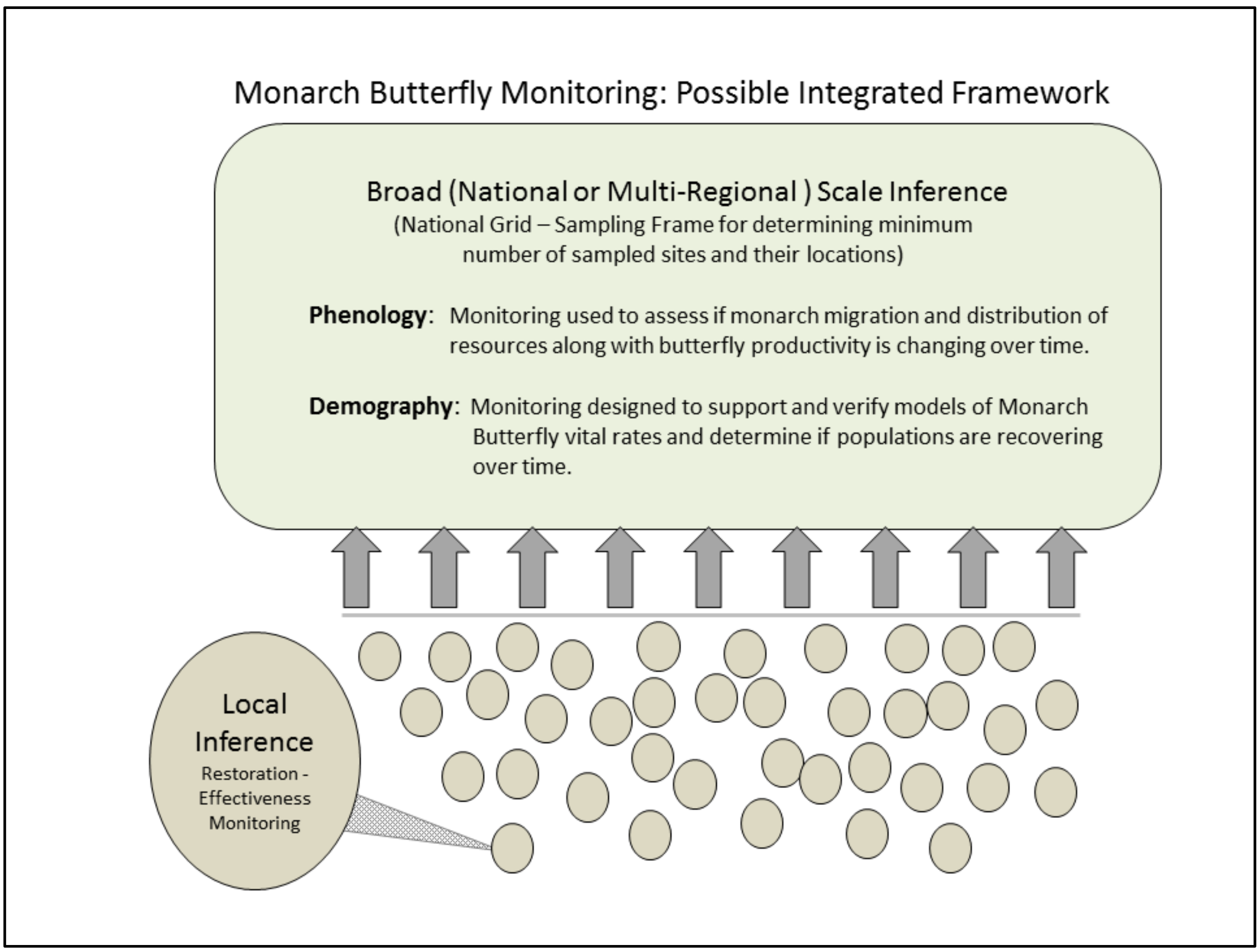

Figure 2. An integrated monitoring program would entail a large scale sampling design, collection of overlapping set of fundamental attributes using existing and appropriate protocols and data portals.

Development of a sampling framework and assignment of sampling locations following a model with established theoretical properties are necessary for arriving at conclusions concerning monarch status and trends across spatial scales. This can be achieved by using a finite grid-based sampling frame for assigning a spatially balanced and randomized ordering of grid 'cells' with the Generalized Random Tessellation Stratified (GRTS) survey design algorithm to allocate sampling locations (Stevens and Olsen 2004; Figure 3). There are many advantages of a GRTS design, including sample site additions and deletions, unequal probability selection of survey locations (e.g., on- vs. off-refuge), and neighborhood-weighted variance estimation, that can improve expected precision of in the measurements or estimation of sampled attributes. This grid-based sampling design provides flexibility in examining monitoring or demographic trends at different scales (Loeb et al. 2015). It also allows legacy data, such as historical or ongoing data collection efforts, including citizen science efforts, to be used to inform status and trends modeling efforts (Overton et al. 1993, Olsen et al. 1999).

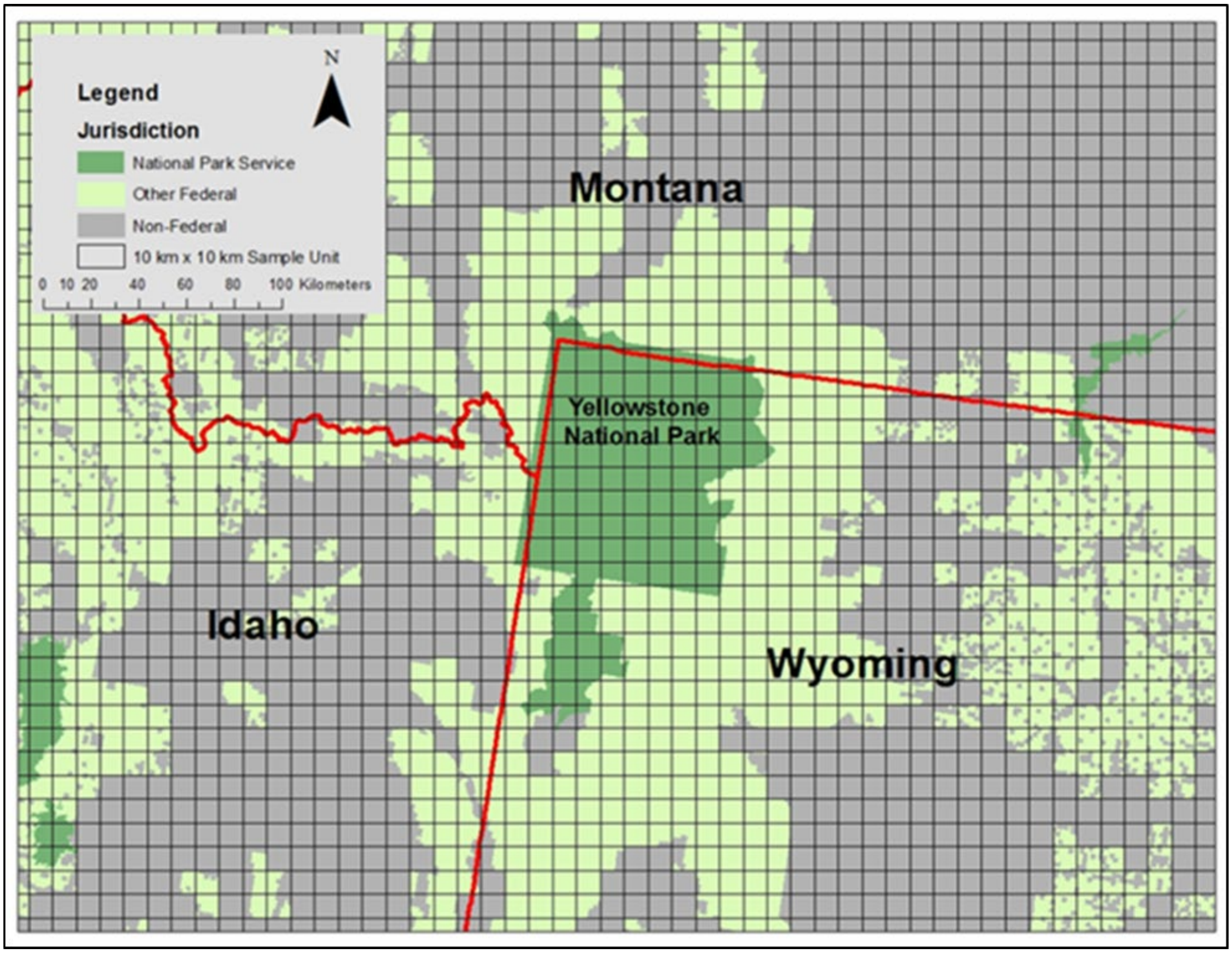

Figure 3. Example grid-based sampling frame, with strata associated with various public lands (from NA Bat Monitoring Sampling frame, Loeb et al. 2015).

Within selected grid cells, target attributes should be measured and recorded according to suitable existing monitoring protocols. Under this strategy, the attributes for monitoring will need to be identified according to the structure and key assumptions of the large-scale models predicting demographic performance (Appendix A) or climate change vulnerability and from those variables that can be measured to inform effectiveness of local habitat management. Study plans will identify the attributes and sub-cell sampling needed to answer integrated research questions (Appendix B).

We foresee that the information serving local monitoring and model use would require recording the location, timing, and number of adults as well as information on egg and larval production (e.g., Oberhauser et al. 2009). Monitoring of the location, phenology, abundance, and type or species of milkweed host plants is also essential information, as are key environmental conditions that may be useful in postulating reasons for not observing expected predictions of monarch's increase despite realized increases in larval food plants and refining predictive models. In summary, probable attributes to be monitored include:

- Presence or absence of larval host plant species and flowering nectar plant species
- Dates of phonological stages of larval host plant species and flowering nectar plant species
- Density of larval-host and nectar plant species
- Dates of presence and absence of monarch butterfly eggs and larvae
- Density of monarch butterfly eggs and larvae
- Dates of presence, absence of monarch butterfly adults during the breeding season
- Density of monarch butterfly adults during the breeding season
- Temperature (covariate)
- Humidity (covariate)
- Soil moisture (covariate)
- Wind speed and direction (covariate)
- Cover (canopy, shrub, any cover affecting milkweed)
- Site descriptors including GIS compatible coordinates and land-use or management history

This monitoring approach, where possible, will benefit from existing programs that engage citizen scientists that collect this type of information, many of which have almost 20 years of data (Appendix C; Prysby and Oberhauser 2004, Cohn 2008, Oberhauser and Prysby 2008).

Data Curation and Program Implementation

There are several independent programs gathering information in various sections of the migration corridors and breeding areas of the monarch butterfly. Most of the information and procedures will be compatible for integrated use (e.g., see Oberhauser et al. 2009, Ries and Oberhauser 2015), but identifying those programs and protocols will be aided by a sampling grid and spatially-explicit information on the existing efforts. A multi-partner team will aid in coordination and further identification of data needs, implementation opportunities, and ultimately data analysis, reporting of findings and feedback to adapt and enhance this proposed integrated approach. The Monarch Joint Venture (MJV) and potentially Monarch-Net, which includes the USGS, FWS, NRCS, and USFS-IP, in addition to many NGO and university partners would be an ideal coordinating body for this effort. Importantly, many of the leaders of existing monarch monitoring programs and the USGS Powell Center Monarch Science Working Group participate through the MJV.

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Appendix A. Hierarchical Modeling for Understanding Spatio-temporal Patterns in Monarch Population Abundance

The response of monarchs to changes in habitat (and other stressors such as changing climate) occurs through changes in vital rates, such as rates of births (fecundity) and deaths (survival). Demographic models for monarchs exist for understanding how vital rates interact to determine population trends. However, the spatio-temporally varying relations between vital rates and environmental characteristics need to be better understood if we want to predict temporal variability in wintering abundance. Bayesian state-space models (e.g., Figure A.1) offer the framework for developing integrated analyses of population count and demographic data (Schaub and Abadi 2011, Pagel et al. 2014). Another approach is to correlate observed numbers with environmental correlates, as done by Zipkin et al. (2012). Demographic data are currently being used to predict monarch population growth using a matrix model in a Bayesian framework (by the Powell Center Monarch Conservation Science Working Group).

In such models, the population (N) in any given year (t) at a particular location (i) comprises incoming adult individuals (N_m, where m is for [e]migrating) surviving from previous generations and new recruits (N_r):

$$N_{i,t} = N_{i,r,t-1} + N_{i,m} .$$

This is typically a stochastic process, characterized by Poisson (or linear) and binomial processes:

$$N_{i,r,t} = \ Poisson(N_{i,t} \times v_{i,t}),$$

$$N_{i,m,t} = \ Binomial(\varphi_{i,t}, N_{i,t-1}),$$

where υ represents the mean number of young per adult individual recruiting (i.e., hatching from the egg and surviving larval stages to adult hood) into the adult population and φ is the probability an existing adult survives from the previous generation. Environmental covariates, along with site and year effects, can be incorporated into each of these processes with generalized linear models.

Given that we are most interested in processes influencing population change, we calculate annual population growth rate $\lambda_{i,t} = {}^{N_t}/_{N_{t-1}}$. Models incorporating the monitoring data on reproduction will inform υ, count data will inform N, and together these will describe changes in species status and the associated factors relating to those changes via λ. Because the count of individuals from any location is generally just a subset of the individuals at a location, we can accommodate impartial detection through another layer in the state-space model. In particular, we assume the underlying population N_t is related in a log-normal fashion to an observed series of counts y_t, with some degree of observation error σ_t:

$$\ln(y_t) \sim Normal(\ln(N_t)\, , \sigma_t^2).$$

The model of the observation process can incorporate such factors as observer experience, effort, wind conditions, and other factors likely to influence detection of monarchs.

We present this outline of our proposed modeling framework to illustrate how inferences are drawn from collected population count data, demographic data, and covariates describing environmental conditions, and hence, the types of attributes that will need to be monitored. We choose a Bayesian modeling approach because the resulting parameter posterior distributions provide a complete characterization of parameter uncertainty that can be seamlessly propagated through our analyses (McGowan et al 2011). In so doing, we faithfully account for uncertainty in population status and trend due to uncertainty in the parameters controlling population change. This modeling framework is flexible in incorporating data gathered at different scales and provides insight into which life stages and life history stages are most affected by changing environmental conditions.

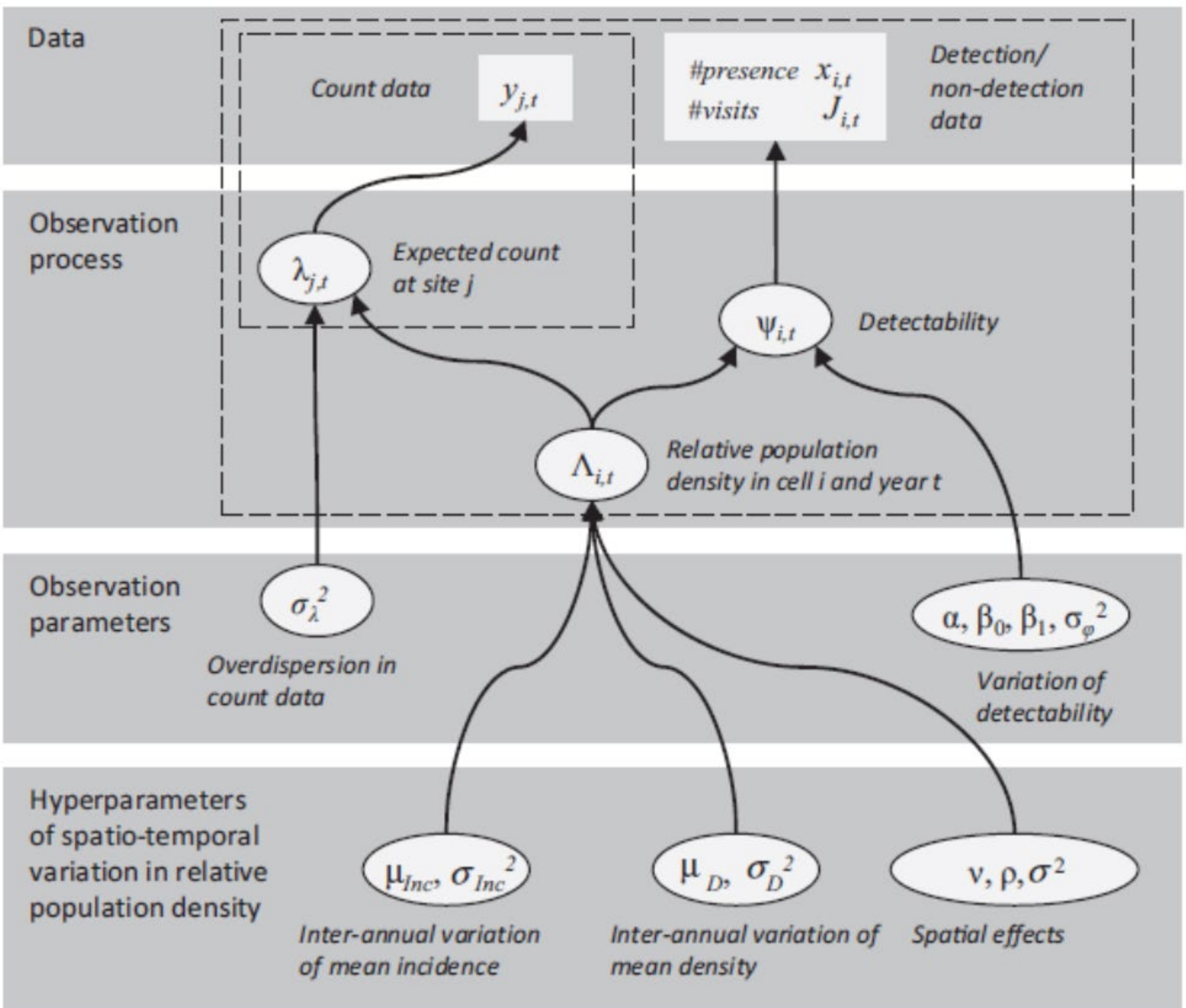

Figure A.1. Structure of an example, advanced hierarchical model describing conditional relationships between data and parameters at various levels. For each grid cell, observation models describe the likelihood of monarch presence or, if monitoring protocol allow, of monarch counts. These observations are characterized by covariate information as seen through the lens of species detectability. (From Pagel et al. 2014)

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Appendix B. The Monarch Monitoring Grid as a Facility for Monarch Conservation Experimentation

Effective management aimed at enhancing successful completion of the yearly life cycle in butterflies often hinges on subtle events. The evolution of management for one particularly well studied butterfly, *Maculinea arion* (Large Blue) in the United Kingdom provides an illustrative example (Thomas et al. 2009). The Large Blue was a carefully monitored and well researched species that nonetheless went extinct in the UK despite management based on extensive research and monitoring that indicated correlations among grazing, host plant availability, and larval presence. The findings lead to recommendations to reduce grazing pressure to enhance host plant growth. Grazing reduction modified microclimates, which resulted in changes in ant community composition that decreased abundance of ant larvae that the Large Blues' larvae fed on, and ultimately contributed to extinction of the Large Blue in the UK. This example illustrates the challenge in understanding the intricacy of ecological relationships and establishing the proper scale and interactions to emphasize in research and management. Existing monarch monitoring and research efforts have pointed to declines in overwinter habitat and milkweed availability as key agents of monarch decline, but much remains to be learned about how those agents affect monarch abundance and, as the Large Blue example illustrates, significant underappreciated agents affecting abundance may yet be elucidated. Establishment of the GRTS sampling scheme and a network of observers can not only facilitate widely distributed and spatially balanced collection of monitoring data, but can also aid in geographically distributing experiments (Borer et al. 2014) that can answer key questions including connectivity for knowing how and where to restore habitats, prevalence and spatial-temporal pattern of threatening pathogens, distribution of genotypes for optimizing long-term conservation, and Best Management Practices (BMP) for producing maximally usable food patches during migration and breeding periods.

In particular, BMPs will depend, in part, on the overall goals of monarch management. While we can agree that one of our goals is to minimize extinction risk for the monarch, population goals might be modifications of that minimal goal. Our current knowledge of monarch population dynamics is based mainly on recent events – declines over the past two decades. However, the historic carrying capacity of the monarch across North America might have been different than in the recent past (Pleasants 2015.). Although recent analyses (Pleasants 2015, Ries et al. 2015) differ in their assessment of how consistently overwinter populations are related to breeding populations in the Midwest, it does appear that Midwest monarch egg production has declined greatly (> 90%, (Pleasants 2015) Figure 14.4) between 1999 and 2012. However, that decline is associated with an historically changed landscape for monarchs in which monarchs have come to rely mainly on common milkweed (*A. syriaca*) as the larval foodplant. This species of milkweed may have been relatively uncommon in the Midwest prior to the twentieth century and today is common in part because of its association with disturbed lands, such as farms and ditches. Common milkweed plants in agricultural settings attract significantly more ovipositions per plant than common milkweeds in non-agricultural settings. One possible reason for this is that the agricultural milkweeds may have higher nitrogen content (Pleasants 2015), an important determinant of larval success in Lepidoptera (Grundel et al. 1998). Higher milkweed nitrogen content may be associated with nitrogen fertilizer application. It is possible that other species of milkweed, such as butterfly milkweed (*A. tuberosa*) may have been the historic mainstay for monarchs in the Midwest and that the abundance of monarchs might have been different historically than in the recent past. This scenario illustrates that the monarch abundance patterns in the 20th and 21st centuries might be quite dependent on, literally, farming an historically less important larval food source, common milkweed. If this was the case, we might look towards a future in which monarch reliance on historic milkweed communities in conservation areas, such as national wildlife refuges, might be seen as a bulwark, or replacement for the agriculturally dependent situation today. One part of our research agenda, therefore, might be to understand historic milkweed community compositions better and how well reliance on species other than *A. syriaca* in conservation settings might meet the goal of minimizing extinction probability of the monarch.

In the following list we provide a synthesis of research topics suggested by the authors of this monitoring strategy (MT), a Conservation Science Working Group (CSG convened at the USGS Powell Center in 2014 and 2015), USFWS Research Priorities (FWS) in 2014, and the Pollinator Health Task Force (PTF) as reported in 2014, with an emphasis on those that might take advantage of the GRTS scheme. The order of the questions and topics does not reflect priority.

(1) What is an accurate number of monarch butterflies per hectare at overwintering sites (CSG)?

(2) Is there a diffuse population of overwintering, diapausing monarchs in Mexico outside of oyamel forest (MT)?

(3) How many stems of milkweed are needed to produce an adult butterfly overwintering in Mexico? What is the spatial distribution (land types; regions) of milkweed density? What is the basic ecology of milkweed species other than common milkweed (CSG, FWS)?

(4) What characteristics of milkweed make a given plant more or less likely to be fed upon by a monarch larva? At what frequency are milkweeds planted under different conditions and arrangements used by monarchs? How consistent are patterns of milkweed use geographically (MT, CSG)?

(5) What are the lipid levels (quality) provided by various nectar food plants? How much nectar can be produced by seed mixes (CSG, PTF)?

(6) What are the Best Management Practices for geographic regions and land-types? How can monarch habitat be integrated into agricultural lands? What and where should habitat be in place to maintain subpopulation connectivity (CSG, FWS, PTF)?

(7) Is microclimate affecting monarch butterfly reproductive success (Weiss et al. 1988, Thomas et al. 2009) (MT)? Sampling across gradients of weather, topography, and

shading; documenting microclimatic variation; and relating milkweed presence, monarch use and fitness as a function of microclimatic gradients might be important.

(8) Under what conditions will monarch reproduction falter (MT)? Gathering detailed data that allow us to determine vital rates (survival through different phases of the life cycle) is useful to address the question of faltering reproduction.

(9) At what population sizes should we expect Allee effects (correlation between population size and individual fitness) to contribute to further declines in monarch butterflies (MT)? Although we think of monarchs as highly mobile, habitat distribution and fragmentation might nonetheless play major roles in determining metapopulation structure and reproductive success of monarchs.

(10) What is the spatial distribution of disease prevalence in monarch populations (MT)? Disease often takes on increasing importance as a source of mortality as species move towards extinction. Sampling for disease agents could be mobilized across the sampling grid.

(11) How much has pesticides affected monarch mortality and habitat degradation (MT, CSG, FWS, PTF)? Refuges might serve as low exposure sites for pesticide effect experiments to quantify this impact on population vital rates or abundance.

(12) What are the effective sizes for monarch subpopulations and when are bottlenecks likely to occur (MT)? Population genetic analyses allow us to determine characteristics of conservation importance, such as frequency and timing of past population bottlenecks and effective population sizes. These could help put current conditions into historic context and could help us understand what prior conditions were associated with population changes.

(13) How will changes in climate influence the distribution food resources for monarch reproduction and migration (MT, FWS)? One subtle effect that might require detailed monitoring and study is phenological mismatching between monarchs and food plants. While efforts exist for monitoring monarchs and milkweeds developmental timing (Journey North, MLMP, National Phenology Network) we might ponder how we might use phenological information in a management context. Agents likely responsible for phenological mismatching would include soil moisture and ambient temperature. Soil moisture affects the ability of plants to survive weather extremes so understanding how we can extend the soil moisture gradients, through management, that milkweeds and nectar plants can reside in is one way in which we can add resiliency to ecosystems to counteract mismatching. Monitoring milkweed and nectar plant distribution along soil moisture gradients could be an important aspect of our management efficacy monitoring. Ambient temperature can directly affect monarch development rates. If development rates of plants and monarchs are differentially affected by soil moisture and temperature, mismatching can emerge. Providing resiliency, in the form of landscape heterogeneity in

soil moisture and microclimate (see 2 above), can be a central management tenet for landscape management for the monarch (Schindler et al. 2015).

(14) What is the role of landscape structure in determining monarch reproductive success? Can we use remote sensing to determine where milkweeds occur (MT, CSG)? The GRTS scheme can certainly help put monarch/milkweed reproductive success into a multi-spatial scale context. However, the ability to understand distribution patterns at multiple spatial scales requires data at multiple scales and often with fairly complete coverage. That coverage can be achieved through sampling and modeling – i.e. determining the continuity of conditions for milkweed and monarch presence through modeling, even if we do not have the actual data on milkweed and monarch presence across scales.

(15) What is the influence of restoration or enhancement of habitats for monarchs on diversity of other pollinators (MT, FWS, PTF)? Increasing milkweed and flowering plant abundance is likely to increase monarch and native bee abundances but not likely to promote native bee diversity if bee nesting habitat diversity is not accounted for during restoration. Examinations of native bee community changes during monarch-oriented restorations can contribute to an adaptive management cycle in which restorations for monarchs evolve into restorations that more fully benefit the general pollinator community.

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Appendix C. Existing Resources Supporting Monarch Monitoring

Table C.1. Protocol materials for monitoring of 8 attributes of monarch butterfly ecology to inform progress and success of habitat restoration or enhancement actions on lands in the National Wildlife Refuge System.

Potential Monitoring Attribute	Applicable Protocol Materials (Citation)[1]	Applicable Projects (NGO/Citizen Science)[1]
Dates of Presence/absence and Phenophases of Food Plant Species	Denny et al. 2014, Journey North	MLMP, Journey North, USA National Phenology Network (USA NPN)
Plant Density by Species	Oberhauser et al. 2009, Alexander et al. 2012, Caldwell and Oberhauser 2014, Borders et al. 2013	Monarch Larva Monitoring Project (MLMP), Journey North; (accuracy problematic)
Dates of Presence/absence of Monarch Eggs	Oberhauser et al. 2009, Journey North	MLMP, Journey North
Monarch Egg Density	Oberhauser et al. 2009	MLMP
Dates of Presence/absence of Monarch Larvae	Oberhauser et al. 2009, Journey North, Denny et al. 2014	MLMP, Journey North, USA NPN
Monarch Larval Density	Oberhauser et al. 2009, Denny et al. 2014	MLMP, USA NPN
Dates of Presence/absence of Monarch Adults	Butterfly Networks, Oberhauser et al. 2009, Journey North, Denny et al. 2014	North American Butterfly Association (NABA) , Butterfly Monitoring Networks (BMN), MLMP, Journey North, USA NPN
No of Adult Monarchs	Butterfly Networks, Oberhauser et al. 2009, Davis and Garland 2002, Denny et al. 2014	North American Butterfly Association (NABA), BMNs, USA NPN

[1] Links to references or programs:
Monarch Joint Venture publications (e.g., Oberhauser et al. 2009, Caldwell and Oberhauser 2014, Borders et al. 2013)
Davis and Garland 2002. An evaluation of three methods of counting migrating monarch butterflies
North American Butterfly Association
Alexander et al. 2012 Detection and Plant Monitoring Programs
Journey North
North American Butterfly Monitoring Network
USA NPN (Denny et al. 2014)