

Abstract

Prior population modeling by Dr. Amy Dykstra suggests that, based off of data from the 2009 and 2010 growing seasons, *Echinacea angustifolia* populations in an area of Western Minnesota are in decline, with smaller remnant populations declining at faster rates than larger ones. This project will use existing and new longitudinal data on *Echinacea* demography at as many remnant sites as possible to estimate population growth using *aster* life history models. Comparing the results of *aster* and matrix population models will hopefully yield insights into the power and functionality of *aster* models, while also hopefully giving the power to see if individual remnant populations are growing or declining.

Project Description

This project, relating to population dynamics of *Echinacea angustifolia* remnants using *aster* models, is the first of two I am proposing for the Summer and remainder of 2016. I intend to write a proposal for a second project, inferring fitness of *Hesperostipa spartea* in experimental plot 1 of the Echinacea Project, by the end of July.

Introduction

In biology, fitness is the net reproductive output of individuals in a population. Most questions in evolutionary biology rely on the idea of fitness. Fitness can be estimated using fecundity and survival data [2] [3]. However most parametric approaches have significant shortcomings [16]. For example, individual fitnesses within a population do not conform to any well-known distributions, and the time-series aspect of fecundity means that the data used to model fitness lack independence. *Aster* life-history models handle these issues using joint conditional probability distributions, where certain life processes (survival and fecundity) are modeled appropriately depending on events in previous life stages [6] [16].

Prior research has been done on the demographics and population dynamics on a perennial tall grass prairie flower, *Echinacea angustifolia* (e.g., density dependence vis-a-vis self incompatibility [19] [20]). One such finding, using matrix population models [2] reliant on data collected from nine distinct prairie remnant populations in Western Minnesota during 2009-2010, found that the *Echinacea* population in aggregate was in decline, with faster decline in smaller remnants [5]. However, in some patches populations were too small to create models for individual remnants. Additionally, the data used to create the projection matrices were based on one year of data, perhaps missing or failing to account for important environmental variance [4].

This project will try to use demographic data from all or most (i.e., those that are sufficiently large) prairie remnants to fit *aster* life history models and calculate growth rates for individual remnant populations. These growth rates (similar to the dominant eigenvalue λ in a matrix projection model) and their variances will be directly compared to those found by Dykstra. The purpose of this is twofold: first, to see the effectiveness of *aster* models in estimating population growth rates, and second, to compare this cohort-based method with the cross-sectional matrix model method, and see if it is able to appropriately overcome the shortcomings in the latter method. Furthermore, one ultimate goal of this project is to be able to estimate with precision the growth rates of populations in individual remnants.

Background

Temperate grasslands are among the most threatened ecoregions on Earth, being converted or altered at rates much higher than they are being designated for protection [9]. North American tallgrass prairie loss has persisted into the new millennium, with smaller patches disappearing or being converted at faster rates than larger patches (some of the latter of which are actually increasing in size). Furthermore, the sizes, edge distance or spatial arrangement of these patches can have significant effect on the establishment or persistence of several native and non-native plant species in prairie remnants, perhaps contributing to remnant growth or decline [11]. The purple coneflower *Echinacea angustifolia* is one such prairie forb at threatened by prairie loss, and various *Echinacea* species (including *angustifolia*) have been used in restoration efforts throughout the plains [8].

With the exception of the matrix model work of Dykstra, I am unable to find work on population dynamics of *Echinacea*. Prior work by the Echinacea Project (Stuart Wagenius and others) on prairie remnants in Douglas and Grant Counties, Minnesota, has shown that local abundance of conspecifics can affect the probability of reproductive failure in *Echinacea* [19] and self-incompatibility and genetic components to kin-incompatibility may heighten this Allee-effect [20]. In general, habitat fragmentation has been widely studied in plant demography and population dynamics. For example, increased edge habitat may expose populations to more inhospitable climate, reducing recruitment [10]. Fragmentation has also been linked to changes in the demographic (stage class) distribution of plants, e.g., with plants in fragments tending to be smaller than in continuous habitat patches [1]. Habitat destruction that comes with fragmentation tends to reduce genetic diversity in remnant populations, making them more susceptible to genetic drift and inbreeding depression ([14] and references within). It should be stressed that these results vary by plant species and environment type, so it is inappropriate to assume similar trends apply to *Echinacea* in prairie fragments without experimentation.

Aster models provide a parametric framework for inferring inference and population growth rates using life history samples [16]. Whereas many studies measure individual components or proxies of fitness rather than holistic reproductive fitness, *aster* models use life history data over the whole of several individuals' lifetime. Furthermore, *aster* models remedy several statistical issues associated with general linear models, such as non-independence of events and sampling distributions with peaks at zero. However, most applications thus far of this type of model have been used solely for estimating (and determining significant predictors of) fitness (e.g., [13] [17] [18]). I have not yet been able to find any papers besides Shaw *et al.*, 2008, which use *aster* models for inferring population growth rates. This has been done in other data-driven ways [3] [12], including using matrix projection models [2]. Further research into these methods will be needed in order to compare them with *aster* modeling.

Goals of research

Dykstra's findings that observed *Echinacea* populations are declining in Douglas County, MN, with smaller populations are declining at a faster rate than larger ones, provide a good foundation for demonstrating an Allee effect. It is possible, however, that when further disaggregated into individual populations, that certain prairie remnants are actually closer to or even significantly greater than $\lambda = 1$, suggesting population growth (although it may require further work to establish population growth if the growth rate is close to 1 [4]). In fact, I would not be surprised if the *Echinacea* population at Staffanson Prairie Preserve was not in decline, as it is actively protected and resembles ancestral prairie more than most other study remnants (see Koper *et al.*, 2010). With the 2009-2010 informed matrix models, the Staffanson population dynamics can not be separated from other large sites. I expect that longitudinal data from ten years at the largest remnant will have enough data to inform an individual model.

It is possible that this analysis will show that prairie remnants of similar size or density have significantly different growth rates. With the knowledge that patches vary in much more than area or number of flowers. (e.g., land use history, use of surrounding land, shape, microclimate, and soil type). *Aster* models for individual remnants can include these variables as predictors, and a gradient of various treatments or remnant aspects can be used as predictors to fit the model to establish relationships between these ecological factors and growth rates. In fact, with a large enough sample, the entire *Echinacea* dataset could be partitioned in other arbitrary ways (e.g., edge vs. non-edge) to study useful ecological questions. At a minimum, the site (i.e., home remnant) of each flower included in analysis should be included as a predictor variable, in order to assess whether or not the site has an effect on fitness in order to see whether or not growth rates differ significantly among sites.

The matrix population model referenced above also includes an elasticity analysis to determine the life stage transitions that have the largest contribution to the growth rate. *Aster* models are able to evaluate the contributions of certain variables, life-history events or treatments to fitness, just as in a linear regression (or general linear model). This may be a way to validate the elasticity analysis, which found that stasis for small basal plants (i.e., plants with 1-3 basal leaves surviving each year) had very large contribution to the growth rate. Comparing seedling or other early-age survival probabilities model coefficients to other life-history rate coefficients would be a logical validation procedure.

Research Plan

Aster models are fitted using cohort data rather than cross sectional data like matrix projection models. The needed data (survival, rosettes, and number of flowering heads) for each flower will be collected for each tagged flower at each site according to a demography protocol implemented in 2014 (titled “demo2014Protocol.docx” on the Echinacea Project website). Complete demography records for study *Echinacea* exists dating back to 2005, with additional incomplete and varied records on individual plant status dating back to 1995. Depending on whether or not prior data exists, seed-set data (number of achenes) may be recorded in certain populations (achene counts are included in models of aphid effects on *Echinacea* fitness done by Shaw *et al.*, 2015). Similarly to in Shaw *et al.*, 2015, annual survival and flowering will be modeled using a Bernoulli distribution, head count will be modeled using a zero-truncated Poisson distribution, and achene count will be modeled using a Poisson distribution.

The models will be implemented using the statistical programming language *R*, using the package *aster* [7]. I have not yet seen any of the demography data from previous years and am not sure how much or what type of preprocessing will be needed to be able to fit a model. As of early July, I do not have plans to collect or use data that we are not already planning on collecting for model predictors. I do not currently plan on using any data from the phenology dataset as predictors in the model, although if I come across relevant and testable hypotheses in a literature search, I may try to incorporate relevant phenology data. I will try to generate population growth rates for all remnant patches with flowering plants between 2005 and 2016; those with too few flowers to fit a model with certainty will be left out of analysis. Model building will be conducted beginning in the Fall of 2016, after the field season has ended and the 2016 year demography data has been collected, at the Chicago Botanic Gardens.

I am still inexperienced in fitting and analyzing *aster* models. It is possible that I have misunderstood certain procedures involved in calculating growth rates. Over the course of the summer, before collection of demography data if time permits, I will read several technical reports published by Shaw *et al.* to supplement their 2008 paper. Lenski and Service, 1982, will probably also need to be revisited several times. These outline how to organize life history data in *R* and how to fit *aster* models. This should be done before any data analysis.

Significance

The Echinacea Project (echinaceaproject.org) is a multifaceted research team with broad interests in prairie conservation, plant genetics, and evolution, with a chief concern being the effects of prairie fragmentation on *Echinacea* populations. Prior work on the population dynamics of *Echinacea* in remnant populations in study areas has been valuable, but sparse, despite being highly relevant to the mission of the project. Being able to estimate growth rates, and thus predict the long term behavior of the populations, would be incredibly valuable. It may also be valuable for management of populations to find what, if any, treatments and management techniques can lead to population growth or slower decline. On a larger scale, the *aster* model is still a relatively new technique, less than a decade from its first publication date. Few, if any, publications have used this method to study population dynamics. The Echinacea Project has a rare, long-term dataset that fits perfectly into this analysis. This study of coneflower remnants may demonstrate the utility and versatility of such models to a larger audience. Furthermore, it would be useful to compare the results given by *aster* models with those findings from the currently widely-used matrix model technique. Given the shortcomings of the matrix model [4] [16], if the *aster* model proves to be a valid alternative, it may be another tool in the arsenal of natural resource managers and population ecologists alike.

Timeline

- July 2016: Read technical reports related to Shaw *et al.*, 2008, as well as reread Lenski and Service, 1982. Familiarize myself with prior years’ data to understand how much reconciliation is needed to aggregate all years’ data.
- August 2016 – September 2016: Likely dates for collecting demographic data in all remnants for 2016 growing season.

- September 2016 – October or November 2016: Organize data from 2016 and prior years into single data structure to fit *aster* model.
- November 2016 and on: Model analysis at Chicago Botanic Garden.

Data Management

Demography data will be collected by team members on Visor devices used for other data collection. Protocol is referenced above. After data has been collected, this data and all prior data (back to 2005) will need to be aggregated into a single file or data frame and put into a uniform framework. This will likely require work to reconcile duplicate plants; I am not sure what the current state of this data is, so I will work to understand that before the end of the summer.

Environmental Impacts

I anticipate no additional environmental impact that was not already planned for in the demography data collection process. Extra power used for data analysis on the computer will be negligible.

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