Testing predictions of bet hedging models with intraspecific variation in seed banks of a California annual

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Abstract

Background/Question/Methods
Seed banks buffer plant populations against environmental variation and population stochasticity. Specifically, delayed germination should evolve to maximize the long-term geometric population growth rate and seed banks should be more likely to be selected for in populations which experience higher levels of interannual variation in fitness. Research with *Clarkia xantiana* ssp. *xantiana* suggests the presence and importance of a soil seed bank in this species. In this study, we leverage intraspecific variation in the seed bank to assess whether seed germination and survival probabilities are consistent with expectations from models for bet hedging. We ask three questions: (1) Is there intraspecific variation in germination probability? (2) Is germination probability negatively correlated with temporal variance in fitness? (3) Is germination probability negatively correlated with seed survival? Finally, we use stochastic population models to calculate the optimal germination strategy and compare these predictions to the observed germination probability.

Results/Conclusions
We use experimental and observational data from a published study on *C. xantiana* demography to fit Bayesian models for population- and year-specific vital rates (seed germination, survival, seedling survival to fruiting, fecundity). We find that germination probability varies among populations of *C. xantiana*, roughly doubling across the range of the species from ~0.10 in western range edge populations and ~0.20-0.25 in eastern range edge populations. Germination probability is not correlated with temporal variance in fitness (Pearson's r = -0.16, 95% credible interval overlaps zero). Germination probability is negatively correlated with seed survival (Pearson's r = -0.16, 95% credible interval does not overlap zero). The optimal germination strategy predicted by population models in which fitness is density-independent do not match the observed germination strategies. Our results provide insight into the selective pressures shaping the evolution of seed banks; our next steps will evaluate whether the observed germination strategies are better predicted by population models with density-dependent fitness or models with predictive germination.

Transcript and description of slides

Slide 1

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Life History Theory and Evolution COS-13” in white. The top of the slide has a gray box with text that reads “Check out the Handouts section of the conference website for a transcript of the talk and descriptions of slides”. The slide has the title of the presentation, “Testing predictions of bet hedging models with intraspecific variation in seed banks of a California annual.” Beneath the title are the names of the authors, Gregor Siegmund and Monica Geber, who are both in the Department of Ecology and Evolutionary Biology at Cornell University. Underneath the list of authors is a cartoon diagram of plant life histories for plants with a seed bank. The cartoon is from John L. Harper’s 1977 book, The Population Biology of Plants.

Transcript: Hello! I’ll be talking about *Testing predictions of bet hedging models with intraspecific variation in seed banks of a California annual*. My name is Gregor and I am a PhD student with Monica Geber. I’m excited to share the work that we’ve been doing with long-term demographic data from the species *Clarkia xantiana*. I also want to note that I uploaded a transcript of the talk and description of my slides to the Handouts section of the conference website and I encourage you to check these out! I’m adding this because I’m not sure how you will know that the file is available.

Slide 2

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Life History Theory and Evolution COS-13” in white. The slide has the title of the presentation, “Testing predictions of bet hedging models with intraspecific variation in seed banks of a California annual.” Beneath the title are the names of the authors, Gregor Siegmund and Monica Geber, who are both in the Department of Ecology and Evolutionary Biology at Cornell University. Underneath the list of authors is the contact information for Gregor Siegmund. There is an email icon and next to the icon is the email, gs589 at cornell.edu. There is a website icon and next to the icon is the website, gregor-fausto.github.io.

Transcript: Because this is entirely online, we won’t have the opportunity to talk in person but I encourage you to reach out to me over email and/or visit my website!

Slide 3

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Life History Theory and Evolution COS-13” in white. The slide is titled “Acknowledgments” and lists the following names: Bill Morris, Dave Moeller, Vince Eckhart, Kate Eisen, Aubrie James, Katie Holmes, Alyssa Anderson, Jasmine Mack, Tom Miller, Steve Ellner, and all Clarkia LTREB field crews! The slide also includes a list of funding sources. These are the NSF GRFP, the Cornell PLSF, and the CALS Alumni

Association Grant. This list also includes NSF LTREB grants 0515428, 1754299. Underneath the list of funding is a group photo of the participatns in the 2019 Bayesian Workshop at the Socio-Ecological Synthesis Center.

Transcript: This research builds on data collected from a long term demographic monitoring project that has involved many people. I'd also like to thank my lab, folks who have provided feedback on different aspects of the project, and my sources of funding and support. Finally, this project was greatly improved by the SESYNC Bayesian Workshop I attended in 2019.

Slide 4

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Background" in white and the words "Questions, Methods, Results" in dimmed white. The slide is titled "Delayed emergence evolved as a life history strategy across the tree of life". The center of the slide has a radial phylogenetic tree depicting the entire tree of life. There are 4 images on the slide, each of which is connected by a line to the corresponding tip on the phylogenetic tree. One image is of a seed, with text underneath that says "dormant seeds". One image is of a bee, with text above that says "bee larvae". One image is of a *Daphnia* ephippium, with text to the right that says Daphnia ephippium. One image is of a *Neurospora crassa* ascospore, with text below it that says ascospore.

Transcript: Taxa across the tree of life strategies that allows them to delay emergence. That this strategy is found across the tree of life suggests these organisms have repeatedly, independently evolved life history patterns that are the result of similar selective pressure.

Slide 5

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Background" in white and the words "Questions, Methods, Results" in dimmed white. The slide is titled "Delayed emergence has ecological and evolutionary consequences". The slide progresses through three images. First, there is a set of three graphs from a paper by McCue and Holtsford in the American Journal of Botany (1998). Each panel is of a different population and shows the sample gene diversity for different loci, comparing the genetic diversity with and without seed banks. Text appears over the graphs saying "maintain genetic diversity. Second, there is a set of four panels from a paper by Cáceres in PNAS (1997). The panels show population growth rates of two species of *Daphnia* under different levels of annual variation. Text appears over the graphs saying "promote coexistence". Third, there is a graph from a paper by Jones and Lennon in PNAS (2010). The graph plots the proportion of microbes that were dormant versus total phosporous for eukarotes and bacteria. Text appears saying "maintain species diversity".

Transcript: Delaying emergence affects many ecological and evolutionary outcomes that affect populations and communities. For example, plant seed banks can help maintain genetic diversity. A study with two Daphnia species suggested that the egg bank helps promote species

coexistence. And a study of microbes suggested that dormancy in microbial taxa is correlated with species diversity.

Slide 6

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Background” in white and the words “Questions, Methods, Results” in dimmed white. The slide is titled “Seed banks allow plants to deal with uncertainty and risk by delaying germination”. Text on the slide says “Two major strategies that contribution to evolution of a seed bank” and has a numbered list. The first point says “Bet hedging proposes that seed banks allow plants to spread risk through time, reducing the variance in fitness over time (Cohen 1966)” and the second point says “Predictive germination suggests that seed banks enable a plastic response, allowing germination into favorable environments (Cohen 1967)”. A list of additional references is located below the text and includes Ellner 1985, Evans and Dennehy 2005, Gremer and Venable 2014, Gremer et al. 2016

Transcript: With these broad themes as the background, I’m now going to focus on plant seed banks for the rest of the talk. Seed banks are a strategy that allow plants to deal with uncertainty and risk. Theory suggests that there are various life history strategies that could contribute to the evolution of a seed bank. One is bet hedging. In this case, seed banks spread the risk of germination through time and reduce the variance in reproductive success. Another is predictive germination, which is a form of plasticity. In this case, seeds hold off on germinating and wait until they are likely to germinate into a favorable environment.

Below, I’ve included some references to theoretical and empirical literature on these topics.

Slide 7

Description of slide: This slide is the same as the previous slide, but the second numbered point is grayed out.

Transcript: We decided to focus on the density-independent model for bet hedging as our “base-case”. We wanted to test the predictions of those models in our system before thinking about models that incorporate density-dependence or models for predictive germination.

In the next few slides, I’ll briefly walk you through a conceptual explanation of the roles of temporal variation and seed bank risk in the bet hedging model.

Slide 8

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Background” in white and the words “Questions, Methods, Results” in dimmed white. The slide is titled “environmental variation is correlated with variance in reproductive success and selects for delayed germination”. On the left hand side of the slide, there are three gray boxes connected by lines with arrows at the ends pointing down. The top box has the text ‘low environmental variation’ and points to a box with the text “low

variance in fitness", which in turn points to a box with the text "favors high germination". On the right hand side, there are three gray boxes connected by lines with arrows at the ends pointing down. The top box has the text 'high environmental variation' and points to a box with the text "high variance in fitness", which in turn points to a box with the text "favors low germination".

Transcript: Bet-hedging models associate variation in the environment with variation in reproductive success. Low levels of variation in reproductive success select for high germination, and high levels of variation in reproductive success select for low germination. Delayed germination is expected to result from uncertainty about reproductive success.

Slide 9

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Background" in white and the words "Questions, Methods, Results" in dimmed white. The slide is titled "A safe seed bank selects for delayed germination". On the left hand side of the slide, there are three gray boxes connected by lines with arrows at the ends pointing down. The top box has the text 'low survivorship in the seed bank' and points to a box with the text "delaying germination is risky", which in turn points to a box with the text "favors high germination". On the right hand side, there are three gray boxes connected by lines with arrows at the ends pointing down. The top box has the text 'high survivorship in seed bank' and points to a box with the text "delaying germination is safe", which in turn points to a box with the text "favors low germination".

Transcript: Bet-hedging models also predict that low survivorship in the seed bank will favor high germination rates because remaining in the seed bank would be risky. Delaying germination, and germinating at lower rates, will be favored when the risk of remaining in the seed bank is low.

Slide 10

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Questions" in white and the words "Questions, Methods, Results" in dimmed white. The slide is titled "Long-term studies of *Clarkia xantiana populations* suggest intraspecific variation in life history". A bullet point on the slide says "Annual plant with a seed bank and populations distributed across the southern Sierra Nevada". On the left below the text, there is a picture of *Clarkia xantiana* flowers along an inflorescence. The flowers are open, and a deep pink color with a small spot outlined in white on the upper petal. The four petals are arranged in an X and are heart-shaped. On the right below the text, there is a topographic map of the region of the Sierra Nevada mountain range in southern California where the populations of *Clarkia* in this study are found. The topographic map is in grayscale, with a river and lake represented as lines and a hatched area. The populations are plotted as orange dots.

Transcript: Let's turn to what prompted us to start down this road. My dissertation advisor, Monica Geber, has been studying *Clarkia xantiana* for decades. *Clarkia xantiana* is an annual

wildflower found in the southern Sierra Nevada with a fascinating history of ecological and evolutionary study. I'm focus on the outcrossing subspecies that has been the focus of demographic studies by Monica and her students and collaborators. Seed burial experiments and annual surveys support the role of seed banks in population dynamics of the plant. The topographic map on the right shows the populations that they've studied in orange.

Slide 11

Description of slide: The slide builds on the previous slide. There are now three circular pictures on top of the map, each of which is a connected to a population by an orange line. The pictures are landscape photos of the area around the corresponding site. The picture on the left corresponds to a site in the west and shows a grassy hill with brown grass, oaks and pine. The middle picture corresponds to a site in the middle of the range and is shows a hill with pines and low shrubs. The picture on the right corresponds to a site in the east and shows a hill with bare ground, some grasses, shrubs, and defoliated pines.

Transcript: To give you a sense of what the plant communities at these populations like, I've included a few photos of the areas around different study sites. In the western part of the range, populations are found among oak–pine woodlands and as you move further east the sites are more in pinyon juniper. Broadly, you also move up in elevation from west to east and from less to more arid.

Slide 12

Description of slide: The slide builds on the previous slide. The map and pictures are now gone and there is additional text and a new graph in place of the map. The first new bullet says "Variation in precipitation increases across the range". The second new bullet says "Population dynamics previously reported in Eckhart et al. (Am Nat 2011)". The graph is of the coefficient of variation in precipitation for 2007-2018. There are two panels, one for the spring and one for the winter. Both plots have easting (km) on the x-axis and the coefficient of variation on the y axis. The plots show general trends where the coefficient of variation increases in populations from west to east.

Transcript: There is also a change in the amount of environmental variation across the range. Here, I'm showing you the coefficient of variation for cumulative precipitation in winter and spring at the populations in the study. You can see that interannual variation in precipitation increases from west to east.

Geographic patterns in the populations I'm discussing today were previously discussed in a 2011 paper.

Slide 13

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Questions" in white and the words "Questions,

Methods, Results" in dimmed white. The slide is titled "Germination probability increases across *Clarkia xantiana's* range". The slide has a graph of the germination probability plotted against position as easting. There are 20 points on the graph, each representing one population in the study. Each point is the median germination probability at the site plotted against the population's value for easting. The points also have credible intervals associated with them, representing uncertainty about the estimate of germination. At the bottom right of the slide, there is text saying "reported in Eckhart et al. (Am Nat 2011)."

Transcript: One of those observations was that germination probability increases from west to east. Here, I'm showing you the probability of germination plotted against easting. The points are the median probability of germination for each population and the lines are credible intervals. You can see that the median probability of germination roughly doubles.

Slide 14

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Questions" in white and the words "Background, Methods, Results" in dimmed white. The slide is titled "What explains the variation we observe in germination probability across the range?". Text below says "Are the life history patterns in *Clarkia xantiana* consistent with predictions of density independent models of bet hedging? We focus on: germination, seed survival in the seed bank, reproductive success".

Transcript: The increase in germination probability across the range prompted us to explore whether bet hedging theory could help explain the life history patterns we observed in *Clarkia xantiana* populations. We started with the density-independent model for bet hedging as our base case, and went about putting together pieces we would need to address predictions from that theory. Specifically, we focused on estimating germination, seed survival in the seed bank, and reproductive success.

Slide 15

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Methods" in white and the words "Background, Methods, Results" in dimmed white. The slide is titled "We use demographic data from experiments and observations to estimate vital rates and reproductive success". Below the title is a timeline marked by years from 2006 to 2018. Below the timeline are colored blocks representing different types of data used in the study; the blocks of color are aligned to the interval of the timeline that the data covers. The first block is orange, runs from 2006 to 2009, and has text that says "seed bag experiments". The second block is blue, runs from 2006 to 2018, and has text that says "observations of seedling survival". The third block is yellow, runs from 2006 to 2018, and has text that says "counts of fruits per plant". The fourth block is pink, runs from 2006 to 2018, and has text that says "counts of seeds per fruit".

Transcript: To estimate each of those elements, we used demographic data from experiments and surveys at each population.

Slide 16

Description of slide: This slide builds on the previous slide. The slide is now titled "Monica Geber and the Clarkia LTREB team buried and recovered seeds at all populations to estimate survival and germination of seeds". The blue, yellow, and pink blocks are dimmed. There are now two pictures next to the orange block with the text "seed bag experiments". The first is a close up photo of seeds of *Clarkia xantiana* on a white background. The second picture is a photo of a mesh seed bag with a labeled metal tag. The bag is laying on top of the soil.

Transcript: We used seed bag burial experiments conducted from 2006-2009 to characterize the germination and seed survival rates for each population. Briefly, these experiments involved burying known numbers of seeds and unearthing them at different points of the year to estimate germination, survival, and to test them for viability.

Slide 17

Description of slide: This slide builds on the previous slide. The slide is now titled "Monica Geber and the Clarkia LTREB team surveyed seedlings, fruiting plants, and estimated seeds per fruit at all populations". The orange block is dimmed and the blue, yellow, and pink blocks are not dimmed anymore. There are now four pictures below the colored blocks. The first is a close up photo of a *Clarkia* germinant. The picture shows the cotelydons. The second is a photo of a *Clarkia* seedling at a stage where the plant has four leaves. The third is the photo of the flowers that was on an earlier slide. The fourth photo is of fruits on a Clarkia plant. The fruits are brown and starting to open at the top, which precedes seed dispersal.

Transcript: We used censuses and surveys conducted from 2006-2018 to estimate the components of reproductive success. In each year, permanent plots were censused for seedlings and adult plants. Populations were also surveyed for fruits per plant and seeds per fruit.

Slide 18

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Methods" in white and the words "Background, Methods, Results" in dimmed white. The slide is titled "The demographic data is structured by population and year". The image below the title is organized into three rows. The top row has the word "Observations" on the left hand side of the slide. To the right of the text are then three groups of blue squares. Each group is composed of eight squares organized into two rows. The top row has white text with n_1, n_2, …, n_n and the bottom row has white text with y_1, y_2, …, y_n. The middle row has the word "Year" on the left hand side of the slide. To the right of the text are then three yellow boxes. Each box has white text. The first is 2006, the second is 2007, and the third is … .The bottom row has the word "Population" on the right hand side of the slide. To the right of the text is one gray box with white text that reads "Black Gulch". The rows are organized so that one yellow blocks is centered underneath each group of blue blocks. The gray

box in the bottom row is centered beneath the yellow box in the middle. Lines connect the gray box to the yellow box in the middle. Three lines connect the yellow box in the middle to the blue boxes in the middle group.

Transcript: The demographic data are organized by population and year, a feature we used to develop models for the estimates related to seeds and reproductive success. As an example, I'm showing a cartoon of the data we use to estimate seedling survival. For each population, we have observations grouped by year starting in 2006. The LTREB field crews counted seedlings in the spring and then adult plants in the early summer.

Slide 19

Description of slide: This slide builds on the previous slide. The slide is titled "We leverage the population and temporal structure of the data and fit hierarchical models to estimate vital rates". To the left of the diagram from the previous slide, there is now an additional diagram enclosed in a gray box. The diagram has four levels of circles. The top level is aligned with the observations. There two circles in this level: one with y and another with n. There is a dotted arrow running from the circle with n to the circle with y. Below the circle with y is a circle with alpha. There is an arrow running from the alpha to the y. Below the circle with alpha is a circle with mu and to the right, below the circle with alpha there is a circle with sigma. There are arrows running from the mu and sigma to the alpha. The circles with mu and sigma are aligned with the year. Below the circle with mu there is a circle with mu-population, and sigma-population. There is an arrow running from this circle to the circle with mu. The circle with mu-population and sigma-population is aligned with population.

Transcript: To take advantage of this population and temporal structure, I fit hierarchical models to the data. On the right hand side of this slide, I added a directed acyclic graph to illustrate the structure of the model I fit to the seedling survival data. We used R and JAGS to fit these models.

Slide 20

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words "Methods" in white and the words "Background, Methods, Results" in dimmed white. The slide is titled "We use demographic data from experiments and observations to estimate vital rates and reproductive success". Below the title is a box that says "seed bag experiments" and to the right of the box there is the text "We use the seed bag experiments to estimate germination and seed survival for each population". Below, there are then three boxes which say "observations of seedling survival", "counts of fruits per plant", and "counts of seeds per fruit". To the right of these boxes there is the text "We use the observations and counts to derive reproductive success for 12 years at each population in the study. Reproductive success is the product of survival, fruit counts, and seed production.

Transcript: In summary, we're using seed bag experiments to obtain estimates for germination and seed survival at each population. And we're using censuses and surveys to obtain estimates for the components of reproductive success.

Slide 21

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Questions” in white and the words “Background, Methods, Results” in dimmed white. The slide is titled “Are life history patterns consistent with bet hedging and can this explain the observed variation in germination probability?”. Text below reads “1. Is germination negatively correlated with temporal variance in reproductive success?” and “2. Is germination probability negatively correlated with seed survival probability?”

Transcript: We use the estimates of the life history components that I just described to ask whether the patterns we observed among populations are consistent with bet hedging. Specifically, we ask two questions that relate the germination probability to the temporal variation in reproductive success and to the seed survival probability.

Slide 22

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Bet hedging theory predicts germination is negatively correlated with temporal variance in reproductive success”. There is a blank graph below the title. There are no points on the graph. The x-axis is labeled “geometric SD of reproductive success” and the y-axis is labeled “mean germination probability”.

Transcript: Bet hedging theory predicts that germination is negatively correlated with temporal variation in reproduction success. To evaluate this prediction, we look at the relationship between germination probability and the geometric standard deviation of reproductive success.

Slide 23

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Prediction: at the population level, germination probability is negatively correlated with the geometric standard deviation of reproductive success”. There is a graph below the title. The x-axis is labeled “geometric SD of reproductive success” and the y-axis is labeled “mean germination probability”. There are 20 gray points on the graph, and a text annotation that reads “Pearson’s r = -0.75”.

Transcript: In terms of our response variables, bet hedging predicts that germination probability is negatively correlated with the geometric standard deviation of reproductive success. On the graph, I’ve simulated what we might expect that relationship to look like for a correlation of negative .75. Each gray point represents one of the 20 populations in the study.

Slide 24

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Germination is slightly positively correlated with temporal variation in reproductive success”. There is a graph below the title. The x-axis is labeled “geometric SD of reproductive success” and the y-axis is labeled “mean germination probability”. There are 20 black points on the graph, and a text annotation that reads “Pearson’s r = 0.28”.

Transcript: Our data are not consistent with the prediction I just showed you on the previous slide. We instead observed that germination is slightly positively correlated with the temporal variation in reproductive success.

Slide 25

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Bet hedging theory predicts germination is negatively correlated with seed survival”. There is a blank graph below the title. There are no points on the graph. The x-axis is labeled “probability of seed survival” and the y-axis is labeled “mean germination probability”.

Transcript: Bet hedging theory predicts that germination is negatively correlated with seed survival. To evaluate this prediction, we look at the relationship between germination probability and seed survival probability.

Slide 26

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Prediction: at the population level, germination probability is negatively correlated with the probability that seeds survive the year in the seed bank”. There is a graph below the title. The x-axis is labeled “probability of seed survival” and the y-axis is labeled “mean germination probability”. There are 20 gray points on the graph, and a text annotation that reads “Pearson’s r = -0.75”.

Transcript: In terms of our response variables, bet hedging predicts that germination probability is negatively correlated with the probability that seeds survive in the seed bank. On the graph, I’ve simulated what we might expect that relationship to look like for a correlation of negative .75. Each gray point represents one of the 20 populations in the study.

Slide 27

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Germination is not correlated with the probability of seed survival in the seed bank”. There is a graph below the title. The x-axis is labeled “probability of seed survival” and the y-axis is labeled “mean germination probability”. There are 20 black points on the graph, and a text annotation that reads “Pearson’s r = -0.03”.

Transcript: Our data are not consistent with the prediction I just showed you on the previous slide. We instead observed that germination is not correlated with seed survival.

Slide 28

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Intraspecific variation in *Clarkia xantiana* life history is not consistent with predictions from density-independent models of bet hedging”. There are two columns below the title. In the left hand column are three graphs, each of which was previously shown in the slides. The first is the one of germination probability plotted against easting. The second is the germination probability plotted against the geometric standard deviation of reproductive success. The third is the germination probability plotted against the probability of seed survival. In the right hand column, there is text corresponding to each graph. The first row reads “Intraspecific variation in germination across the range”. The second row reads “Germination is slightly positively correlated with temporal variation in reproductive success”. The third row reads “Germination is not correlated with seed survival”.

Transcript: To summarize, from what I’ve shown you so far, it seems that intraspecific variation in *Clarkia xantiana* life history is not consistent with predictions from density-independent models of bet hedging. Although we see intraspecific variation in germination across the range, germination is not negatively correlated with either temporal variation in reproductive success or with seed survival.

Slide 29

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Next steps could include partitioning variation in reproductive success, incorporating density-dependence, and assessing evidence for predictive germination”. The slide is blank.

Transcript: I want to return to the idea that evaluating predictions of the density-independent model was our ‘base case’. There are a few next steps we’re considering to dig deeper into what we’ve found so far. These could include partitioning variation in reproductive success, incorporating density dependence, and assessing evidence for predictive germination. I’ll end my presentation today by introducing one of these.

Slide 30

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Results” in white and the words “Background, Questions, Methods” in dimmed white. The slide is titled “Next steps could include partitioning variation in reproductive success, incorporating density-dependence, and assessing evidence for predictive germination”. Below the title is a graph. The x-axis on the graph is titled Component and has 6 factors: Variance in survival, Variance in fruits, Variance in seeds, Covariance in survival and fruits, Covariance in survival and seeds, and Covariance in fruits and seeds. The y-axis is titled Variance or covariance. For each factor on the x axis, there are 20 points on the y-axis. All points on the graph are connected by lines. In addition to the graph there is text that reads “Large variance in reproductive success is driven by populations with high variance in seedling survival to fruiting”.

Transcript: I’m showing you our initial steps into partitioning the observed variance in reproductive success. I’m showing you a parallel coordinates plot where I’ve split up all the component geometric variance and covariances that contribute to the total geometric variance in reproductive success. The plot suggests that high variance in seedling survival to fruiting is a major contributor to total variance in reproductive success for several populations. Exploring how these variance components are related to germination might help us understand why we’re not observing the negative correlations we expect.

Slide 31

Description of slide: The slide has a white background and a pink quarter circle in the top left corner. The quarter circle contains the words “Life History Theory and Evolution COS-13” in white. The slide has the title of the presentation, “If you’re here, thank you for taking the time to watch this presentation! I encourage you to contact me with questions or feedback!” Underneath the title is the contact information for Gregor Siegmund. There is an email icon and next to the icon is the email, gs589 at cornell.edu. There is a website icon and next to the icon is the website, gregor-fausto.github.io.
Transcript: If you’ve made it this far, thank you for taking the time to watch or listen to this presentation! Please reach out to contact me with questions or feedback. I would love to hear your thoughts as I move forward with this project!