Grasshopper Phenology and Climate Change

Overview

Over the last century, average global surface temperatures have increased by 0.74°C. This warming has had a variety of impacts on species; affecting their development, distributions and relative abundances. In this lab, using actual weather station temperature data, we explore how climate has changed along an elevational gradient in the Front Range of Colorado over the last 50 years. We also compare the results of a historical survey to a modern resurvey of grasshoppers collected near each of these weather stations to determine how the timing to adulthood of grasshoppers has been affected by recent warming. To understand how temperature affects grasshopper development, we introduce growing degree days (GDDs) as a measure of thermal energy available to plants and ectotherms, such as insects and reptiles, for growth and development. Finally, we use the GDDs concept to make predictions about grasshopper development given future warming scenarios.

Key terms: climate change, growing degree days, life zones, phenology

Goals

1) To introduce students to the effects of climate change on organisms, the life zone concept, and growing degree days

2) To allow students to use actual climate and grasshopper survey data to evaluate recent climate change and its effects on insect and plant development

3) To provide students the tools and concepts necessary to understand and evaluate how future climate change may affect the development, number of generations and distribution of organisms

Before coming to lab

In order to progress effectively and better understand the concepts covered in this lab, it is expected that each student will have read the pre-lab sections on life zones, climate change, and growing degree days that are available on the project web site before coming to class (see link below). After reading these sections, print and bring completed pre-lab questionnaire to class.

http://ghopclimate.colorado.edu/lab_intro.html

Grasshoppers and Climate Change Lab

The following activities use actual climate data, a survey of grasshopper communities conducted 50 years ago and a new resurvey program to 1) examine how climate has changed along an elevational gradient, 2) determine how the timing to adulthood (phenology) of grasshoppers in different communities have be altered over the last 50 years and 3) model how grasshoppers development may continue to be affected given future warming scenarios.

Part 1. How has climate changed along an elevational gradient in the Rocky Mountains of Northern Colorado?

As one moves up along an elevational gradient, the average yearly temperature declines (**Figure 1**), while the average precipitation (as rainfall and snow) typically increases. These changes in temperature and precipitation largely determine the types of organisms and thus life zones found along the gradient.

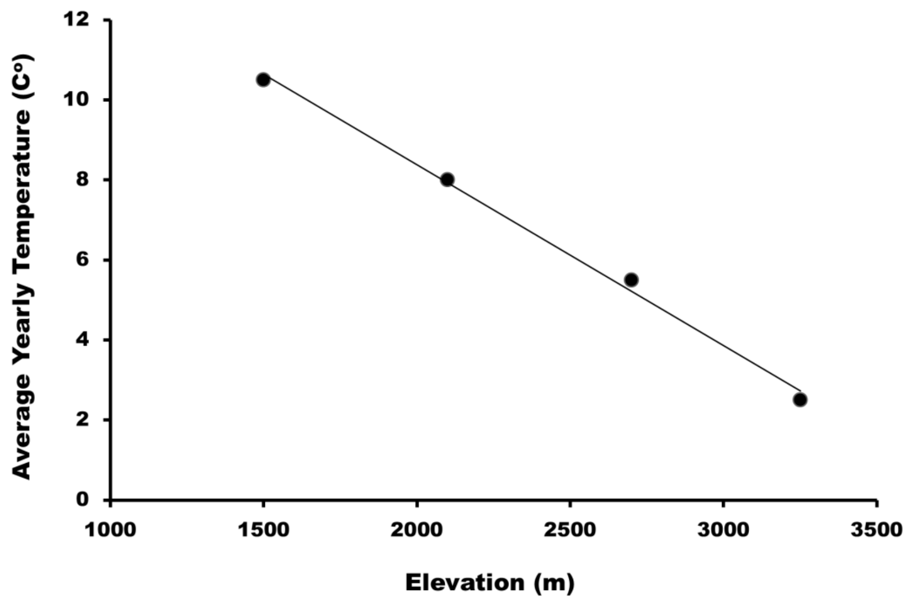
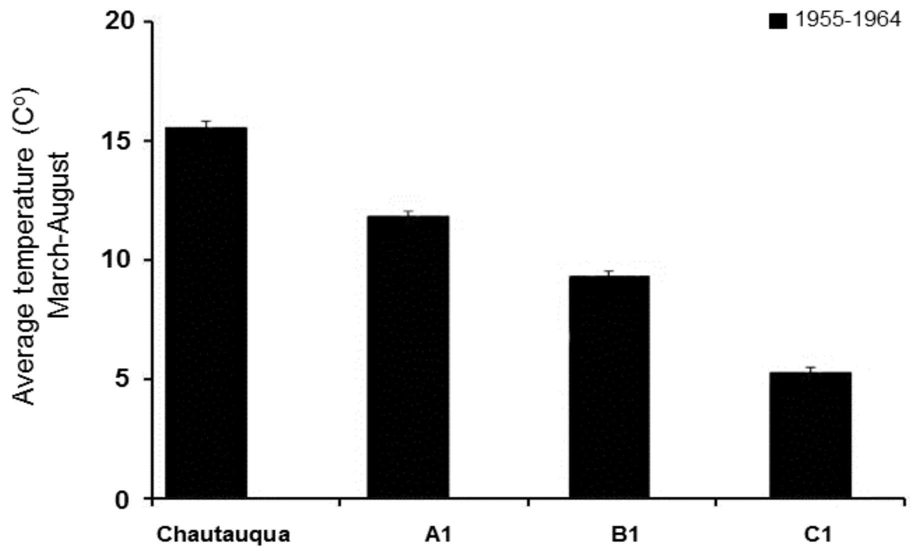


Figure 1. Average yearly temperature and elevation along a high plains to subalpine gradient in Northern Colorado.

For this study, we are interested in the average seasonal temperatures that occur from March 1st to August 31st at each of the study sites. These temperatures are important because in March temperatures begin to reach and exceed the lower base temperature required for grasshopper development (12^{0}C) and by the end of August, all grasshopper species of interest have reached adulthood. **Figure 2** shows the 10 year average daily temperatures that occurred during the spring and summers (March to August) around Alexander's original study (1959-1960).



Elevation (m):	1752	2195	2591	3048
Life zone:	Plains	Foothills	Montane	Subalpine
Actual difference (C°): (1999-2008 minus 1955-1964)	_______	_______	_______	_______

Figure 2. The average daily March to August temperatures that occurred during 1955 to 1964.

1. Using the Excel sheet titled "Yearly Averages & Daily Means Chaut to C1" (available at the lab web site), calculate the average spring to summer temperatures during 1999-2008. Subtract the 1955-1964 values from the more recent 1999-2004 values to determine how the daily seasonal temperatures have changed. Return to **Figure 2** above and report the actual differences (in degrees C) between these two time periods. In **Figure 2**, draw what the 1999-2008 bars would look like to the right of the 1955-1964 bars.

As a point of reference, a 0.75^0C difference would mean that the *average daily temperatures* during the spring and summers of 1999-2008 would be 1.35^0 F greater than 50 years prior.

2. Given the actual warming patterns along the gradient, discuss within your group (and write below) how you might predict grasshopper phenology (timing to adulthood) might change along the gradient. While the average global surface temperatures have increased by 0.75C, some sites along the gradient (during the spring to late summer) have increased by more than this. Given the average daily temperature increase at B1, by how many days or weeks might you predict these grasshoppers to advance their timing to adulthood?

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Part 2. How have grasshopper communities responded to non-uniform warming along the elevational gradient?

During 1959-1960, Gordon Alexander and his team surveyed grasshoppers on a weekly basis at several sites and recorded the species that were present and their developmental stages. **Table 1** show the 4 main collecting sites and the common species used in his study

Table 1. Grasshopper communities and phenological advancement.

Station	Species	Earliest ordinal date of adult appearance (1959-1960)	Change in timing to adulthood	Number of species advancing
Chautauqua Mesa (1752 m)			**-2007-**	
	Aeropedullus clavatus	152	________	
	Melanoplus confusus	155	________	
	Melanoplus sanguinipes	176	________	
	Melanoplus bivittatus	181	________	
	Melanoplus dawsoni	186	________	
	Hesperotettix viridis	186	________	_____/ 6
		Average advancement=	________	
Station A1 (2195 m)			**-2007-**	
	Aeropedullus clavatus	167	________	
	Melanoplus confusus	167	________	
	Melanoplus dodgei	174	________	
	Melanoplus sanguinipes	183	________	
	Cratypedes neglectus	195	________	
	Cammula pellucida	195	________	
	Hesperotettix viridis	202	________	
	Melanoplus bivittatus	202	________	_____/ 8
		Average advancement=	________	
Station B1 (2591m)			**-2006-**	
	Aeropedullus clavatus	172	________	
	Melanoplus dodgei	172	________	
	Cammula pellucida	202	________	
	Circotettix rabula	207	________	
	Melanoplus dawsoni	215	________	
	Melanoplus packardii	216	________	
	Chloealtis abdominalis	216	________	_____/ 7
		Average advancement=	________	
Station C1 (3048 m)			**-2006-**	
	Melanoplus dodgei	182	________	
	Melanoplus fasciatus	202	________	
	Cammula pellucida	209	________	
	Chloealtis abdominalis	216	________	_____/ 4
		Average advancement=	________	

* Note that the Alexander (1959-1960) and the current survey sampled roughly every 7 days so the values must exceed 7 days for grasshoppers to be considered at least a week early or late.

Assigned site:___________________

Part 2 instructions: Using the sampling sheet associated with your site (Appendix 1-4) and a provided field guide to grasshoppers, you will process sampling bins (associated with different ordinal dates) to determine which species were present as adults during each weekly sampling period during 2006 or 2007. Once you have determined the current timing to adulthood for each grasshopper species, subtract the original 1959-1960 ordinal date to adulthood from each ordinal date in the current survey. Negative values (–) denote that the species are currently becoming adults earlier; while positive (+) values denote that the species are becoming adults later in the year than they previously were.

1. You will have a chance to present the results associated with your site to the class, but before you do so, answer the following questions.

i. How many species advanced their timing to adulthood out of the number of focal species at your site? _______/_________. What was the average number of days that the community advanced? __________

ii. If it takes grasshoppers a certain number of growing degree days to reach adulthood, how might the pattern of warming at your site help explain any community level patterns of advancement?

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iii. Are there any other general thoughts or comments that resulted from the group discussion?

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iv. After all groups have presented, do the overall findings support your predictions of which communities advanced the most? Why or why not?

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Use your recorded measures of grasshopper advancements at your site to fill in ***Table 1*** *above. Use this table to record the relative phenological advancements associated with the other sites when the other groups present their findings.*

Part 3. How might grasshopper phenology be affected by future estimates of climate change?

Growing degree days (GDDs) are a measure of the amount of energy available to an organism for growth and development. The number of GDDs associated with a given day is calculated as follows.

$$\text{GDDs} = \left[\frac{(T_{\text{MAX}} + T_{\text{MIN}})}{2} \right] - T_{\text{BASE}}$$

Equation 1.

With $\mathbf{T_{max}}$ being the hottest temperature of the day, $\mathbf{T_{min}}$ being the coldest temperature of the day and $\mathbf{T_{base}}$ being the lower threshold temperature that must be reached in order for an organism to grow and develop ($\mathbf{T_{base}} = 12^0$C for grasshoppers). In sum, the number of GDDs for any given day is simply the average number of temperature degrees above $\mathbf{T_{base}}$ that occur over a given 24 hour period. See GDDs section of pre-lab for more information.

Figure 3 below shows how the number of GDDs that occur each day accumulate over a year. Examine Figure 4 and be sure that you can answer the following questions (no need to write these answers down): i) How many GDDs accumulate by the end of the year? ii) Why do GDDs not accumulate during the winter months? iii) When is the rate at which GDDs accumulate highest and why? iv) If a grasshopper requires 800 GDDs to become an adult, at the beginning of which month would it become an adult?

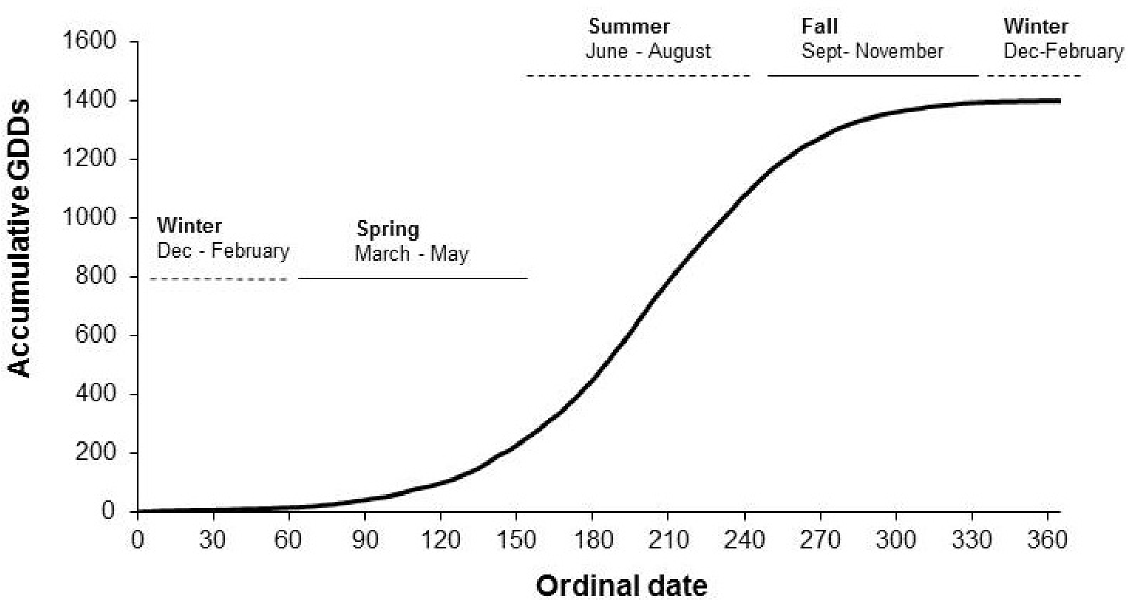

Figure 3. Growing degree day accumulation pattern in a lowland prairie in Colorado.

Calculating GDD patterns at your site. **Assigned site:_____________________**

1. Open the Excel sheet titled "Yearly and Average Min & Max Chaut-C1". This file is available on the main lab web site and contains the average min and max daily temperatures (^{0}C) associated with each ordinal day at each site from 1953 to 2008.

i. Choose the orange tab at the bottom left of the Excel sheet associated with your site (Chautauqua Mesa, A1, B1, C1) to calculate and record the total number of GDDs that accumulate *at your site* by the end of a typical year (ordinal day 365). To answer this question, you will need to determine the number of GDDs associated with each ordinal date and then sum these values over the year. All groups will report the total number of GDDS associated with their site to the class.

IMPORTANT: Before you sum GDDs over the year, be sure to convert any daily negative GDD values to 0 (zero) as organisms will not experience negative development. To make negative values into 0s, in cell 5 of column H (H5), type the following equation, =IF (G5<0, 0, G5), hit return, and then scroll this equation all the way down to day 365. This "if-then" statement says, if the value associated with G5 is less than 0, make it 0, if not keep the value as G5.

Total number of GDDs

Chautauqua Mesa: ___________ A1: ____________ B1: ____________ C1: _______________

2. As a percentage, how much more energy is available for development in Chautauqua Mesa (the plains life zone) relative to C1 (the subalpine)? Thinking about how GDDs are calculated, describe what must be going on to produce this pattern?

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3. Having calculated the number of GDDs per ordinal date for your site, use the column titled "Accumulative GDDs" to calculate how GDDs accumulate over a year. To determine the total number of GDDs that have accumulated by a given ordinal date, in cell 6 of column k (k6), type the following equation, =H6 +K5, hit return, and then scroll this equation all the way down to day 365. For each ordinal date (K_x), this equation adds the number of GDDs that occurred during that 24 hour period (H_x) to the total that occurred previously (K_{x-1}).

Next, in Excel create a graph that shows "Ordinal Date" on the x-axis and "Accumulative GDDs" on the y-axis. To do this, select both column J, rows 4-369 and column K, rows 4-369 and then choose from the top menu "insert → scatter → scatter with smooth lines".

i. Use **Figure 4** to plot when GDDs begin to accumulate at your site, the total number of GDDs accumulated by ordinal date 365 and the corresponding accumulation pattern (from the Excel graph you produced above). Each group will draw the pattern associated with their site on the board. *Be sure to include the GDD accumulation patterns of all sites on **Figure 4**.*

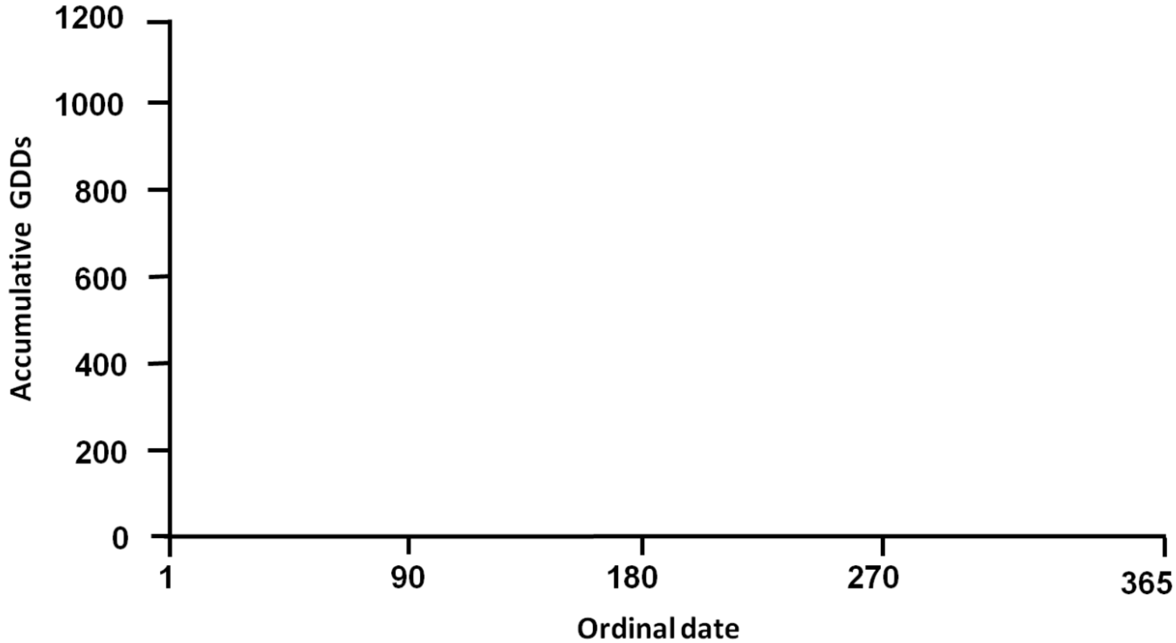

Figure 4. This figure illustrates the GDD accumulation patterns at the each of the 4 sites.

ii. After GDD accumulation patterns at all sites are included in Figure 4, compare the accumulation patterns at all sites. Describe how are they similar and how do they are different.

4. While it is not known how temperatures will continue to increase, the lowest, average and highest emissions scenarios predict that by 2100, global temperatures will increase by 1, 3, and 5 ^{0}C, respectively (http://www.ghgonline.org/predictions.htm). Using the Excel sheet with the climate data for this transect, calculate how GDDs would accumulate at your site given the three scenarios. While warming may be more apparent during certain seasons or months, for simplicity's sake, assume that the average daily temperature of each ordinal date is warmer by 1, 3 or 5 ^{0}C degrees.

i. What is the total number of GDDs that would accumulate over a year at your site given the three warming scenarios?

Current total GDDs: __________ 1^{0}C degree scenario: __________

3^{0}C degree scenario: __________ 5^{0}C degree scenario: __________

ii. In **Figure 5** below, graph the current GDD accumulation pattern at your site, then graph the accumulation patterns associated with the 1, 3 and 5^0C warming scenarios. The data can be plotted using Excel columns AG to AK. Be sure to label the scale on the y-axis (which will be site specific) and to note which GGD accumulation pattern is associated with each scenario. HINT: *Before settling on the scale on the Y-axis, determine how high the scale will need to be given the +5 degree warming scenario*.

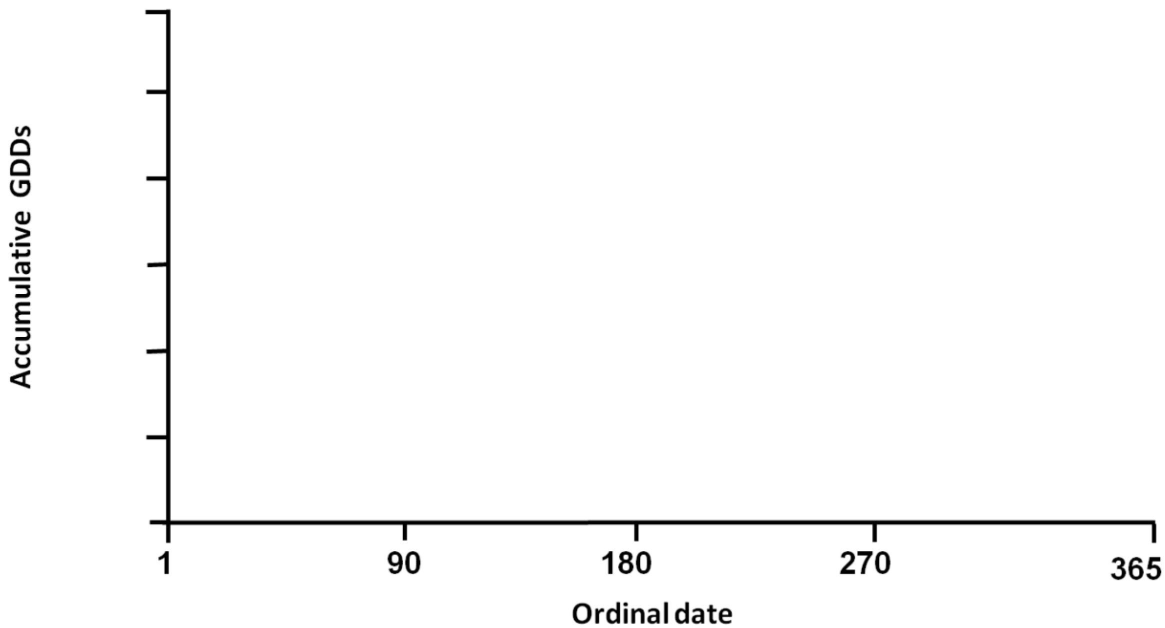

Figure 5. The GDD accumulation pattern based on the last 50 years and those projected by the 1, 3 and 5^0C warming scenarios.

iii. If a grasshopper requires a given number of GDDs to reach adulthood at your site, by how many days would we expect this grasshopper to advance its phenology (timing to adulthood) given the different warming scenarios? For this exercise use either 450, 330, 280 or 120 GDDs depending on whether your site is Chautauqua Mesa, A1, B1 or C1, respectively, as the "given _____GDDs" below, as these are the average GDDs required by grasshoppers at these sites to become adults.

Current ordinal date to adulthood given _______ GDDs is _______________

Advancement (in days) given the 1^0C degree scenario: _______________

Advancement (in days) given the 3^0C degree scenario: _______________

Advancement (in days) given the 5^0C degree scenario: _______________

iii. Given the advancement to adulthood of the grasshoppers in the 2006-2007 surveys (**Table 1** above) associated with current warming patterns, do future projected changes in the timing to adulthood seem reasonable given the 2100 scenarios? Why or why not?

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Homework: Multiple generations and shifting ranges

In this lab exercise, you used grasshopper communities along an elevational gradient to explore how the developmental rate and, in turn, the phenology of plants and ectotherms (such as insects, fish and reptiles) can be affected by a warming climate. That is, as temperatures warm, annual biological events that require a given amount of thermal energy (GDDs) occur sooner. Still, there are at least two other ways that organisms can be affected by warming that occurs within a given area. A warming climate can also affect the number of generations that a species can undergo per year and their spatial distribution.

Multiple generations

The number of generations a species may undergo during a year can be species specific and at times, it can vary among populations within a given species. For example, in temperate regions such as Colorado, the growing season is relatively short and the amount of available thermal energy does not make it viable for grasshoppers to undergo more than one generation per year. However, in Mexico, California and Arizona where it can be much warmer, grasshoppers can have more than one generation per year.

Changing distributions

As the climate of an area warms, communities will be exposed to higher daily temperatures and thus to an increase in the amount of GDDs that is available for development. For some organisms, these higher temperatures will exceed their acceptable thermal ranges and they will no longer be able to inhabit the area. For other species, the warming temperatures may create hospitable areas that are now associated with temperatures within their acceptable ranges and that have enough GDDs for them to complete development and reproduce. These later species may then move into these new areas.

Homework questions:

Use the Excel climate data you used for the exercise above (titled “Yearly and Average Min & Max Chaut-C1”) to answer the following questions.

1. Bark beetles have been determined to have a lower temperature threshold limit of 5^0C and require 660 GDDs to complete a single life-cycle (from egg to adult). On very warm years in the sub-alpine, researchers have determined that bark beetles can have two distinct generations. How much warmer on average (+1, +2, +3) would sub-alpine habitats in the Front Range (C1) need to become for this species to be able to consistently complete two life-cycles per year? Explain your reasoning.

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To learn more about pine beetle and climate change, see:
http://learnmoreaboutclimate.colorado.edu/full-scientist-interviews-and-links/pine-beetle-epidemic

2. A researcher is studying a butterfly that is found in the foothills near Boulder, Colorado. From laboratory studies, she determined that the lower temperature threshold for this butterfly is 10^0C and that the butterfly requires at least 1,000 GDDs to successfully complete its life-cycle (from egg hatch in spring to an adult that has laid all of its overwintering eggs in late summer). How much warmer on average (+1, +2, +3) would montane habitats need to become for this species to be able to complete its life-cycle in the montane life zone? Once you have determined the minimum amount of warming that would be necessary to complete its life cycle in the montane, estimate the ordinal date that this species would be able to complete its life cycle (i.e., that is associated with roughly 1,000 GDDs). Explain your reasoning.

3. Write a short essay below that summarizes the key findings associated with this lab on grasshopper communities along the elevational gradient and climate change (parts 1-3 of the lab). How do you think advances in phenology could impact the grasshopper communities? Are there any other ways that we have not discussed in which grasshoppers could be affected by future climate change?

Appendix 1

Data Sheet for Chautauqua Mesa, Plains (1,752m or 5,750ft)

Bin number					**1**	**2**	**3**	**4**	**5**
Calendar date 2007	13-May	21-May	30-May	4-Jun	13-Jun	18-Jun	25-Jun	2-Jul	9-Jul
Ordinal date	**135**	**141**	**150**	**155**	**164**	**169**	**176**	**183**	**190**

Species in study 2007					Start				
*Aeropedullus clavatus**	**No adults found**	**6**	**10**	**14**			**20**	**20**	**16**
Melanoplus confusus				**6**			**10**	**8**	**4**
Melanoplus sanguinipes									
Melanoplus bivittatus									
Melanoplus dawsoni									
Hesperotettix viridis									

* some data has been filled for these species

Species in study	**Ordinal date to adulthood 2007**	**Ordinal date to adulthood 1959-1960**	**Difference between surveys** (current survey-previous)**
Aeropedullus clavatus		152	
Melanoplus confusus		155	
Melanoplus sanguinipes		176	
Melanoplus bivittatus		181	
Hesperotettix viridis		186	
Melanoplus dawsoni		186	
		Average =	

You may encounter species not on the list. These are uncommon, rare or accidental species that get blown in.

These species will not be included in this resurvey project.

** NOTE: In order to be of consequence, the difference between 1959-1960 & 2007 ordinal dates must be greater than seven because sampling was done on a weekly basis.

Additional notes: The speciemens you are processing in this lab do not include juveniles.

Appendix 2

Data Sheet for A1, Foothills (2195m or 7201ft)

Bin number					**1**	**2**	**3**	**4**	**5**
Calendar date 2007	1-Jun	6-Jun	11-Jun	18-Jun	25-Jun	2-Jul	9-Jul	16-Jul	24-Jul
Ordinal date	**152**	**157**	**162**	**169**	**176**	**183**	**190**	**197**	**205**

Species in study 2007					**Start**				
*Aeropedullus clavatus**	**No adults found**	**2**	**3**	**8**			**15**	**10**	**8**
Melanoplus confusus									
*Melanoplus dodgei**		**3**	**5**	**14**			**10**	**8**	**5**
Melanoplus sanguinipes									
Cratypedes neglectus				**8**					
Camnula pellucida									
Hesperotettix viridis									
Melanoplus bivittatus									

*some data has been filled for these species

Species in study	**Ordinal date to adulthood 2007**	**Ordinal date of adulthood 1959-1960**	**Difference between surveys (**current survey-previous)**
Aeropedullus clavatus		167	
Melanoplus confusus		167	
Melanoplus dodgei		174	
Melanoplus sanguinipes		183	
Cratypedes neglectus		195	
Camnula pellucida		195	
Hesperotettix viridis		202	
Melanoplus bivittatus		202	
		Average =	

You may encounter species not on the list. These are uncommon, rare or accidental species that get blown in. These species will not be included in this resurvey project.

**NOTE: In order to be of consequence, the difference between 1959-1960 & 2007 ordinal dates must be greater than seven because sampling was done on a weekly basis.

Additional notes: The speciemens you are processing do not include juveniles. There are currently 16 species that are residents at this site.
In 1989, a large fire (the Back Tiger fire) burned this site and non-native brom grasses were planted in the area to control errosion. This has modified the habitat a great deal.
http://www.bouldercounty.org/live/environment/land/pages/blacktigerfire.aspx

Appendix 3

Data Sheet for B1, Montane (2591m or 8500ft)

Bin number				**1**	**2**	**3**	**4**
Calendar date 2006	2-Jun	8-Jun	15-Jun	22-Jun	29-Jun	7-Jul	13-Jul
Ordinal date	**153**	**159**	**166**	**173**	**180**	**188**	**194**

Species in study 2006				**Start**			
*Aeropedullus clavatus**	**No adults found**	**9**	**20**			**16**	**15**
*Melanoplus dodgei**		**9**	**8**			**11**	**8**
Camnula pellucida							
Circotettix rabula							
Melanoplus dawsoni							
Melanoplus packardii							
Chloealtis abdominalis							

* some data has been filled for these species

Species in study	**Ordinal date to adulthood 2006**	**Ordinal date to adulthood 1959-1960**	**Difference between surveys** (current survey-previous)**
Aeropedullus clavatus		172	
Melanoplus dodgei		172	
Camnula pellucida		202	
Circotettix rabula		207	
Melanoplus dawsoni		215	
*Melanoplus packardii****		216	
Chloealtis abdominalis		216	
		Average=	

You may encounter species not on the list. These are uncommon, rare or accidental species that get blown in. These species will not be included in this resurvey project.

* NOTE: In order to be of consequence, the difference between 1959-1960 & 2006 ordinal dates must be greater than seven because sampling was only done weekly.
*** Value here is correct relative to the 2010 Nufio et al publication

Additional notes: The speciemens you are processing in this lab do not include juveniles.

Appendix 4

Data Sheet for C1, Subalpine (3,048m or 10,000ft)

Bin number		**1**	**2**	**3**	**4**	**5**	
Calendar date 2006	14-Jun	21-Jun	29-Jun	6-Jul	12-Jul	19-Jul	26-Jul
Ordinal date	**165**	**172**	**180**	**187**	**193**	**200**	**207**

Species in study 2006		**Start**					
Melanoplus dodgei	**No adults found**						**4**
Melanoplus fasciatus							**6**
Camnula pellucida							**15**
Chloealtis abdominalis							**6**

Species in study	**Ordinal date to adulthood 2006**	**Ordinal date to adulthood 1959-1960**	**Difference between surveys*** (current survey-previous)
Melanoplus dodgei		182	
Melanoplus fasciatus		202	
Camnula pellucida		209	
Chloealtis abdominalis		216	
		Average =	

You may encounter species not on the list. These are uncommon, rare or accidental species that get blown in. These species will not be included in this resurvey project.

* NOTE: In order to be of consequence, the difference between 1959-1960 & 2006 ordinal dates must be greater than seven because sampling was only done weekly.

Additional notes: The speciemens you are processing in this lab do not include juveniles.