3/03/16

Results:

* Figure 4: Germination rate for each population of each species in gray, averages for each origin in color. Standard error bars are shown. See Table 1 for species code legend.
* Figure 5: germination rate by origin, and across stratification length and temperature treatments for each species, with standard error bars. Note the variable y-axis scale. See Table 1 for species code legend.
* Figure 6: Germination date for each population of each species in gray, averages for each origin in color. Standard error bars are shown. See Table 1 for species abbreviation legend.
* Figure 7: Germination date by origin, and across stratification length temperature treatments for each species, with standard error bars. Note the variable y-axis scale. See Table 1 for species code legend.
* Figure 8: Growth rate for each population of each species in gray, averages for each origin in color. Standard error bars are shown. See Table 1 for species code legend.
* Figure 9: Growth rate by origin, and across stratification length temperature treatments for each species, with standard error bars. Note the variable y-axis scale. See Table 1 for species code legend.
* Figure 10: coefficient of variation
  + 10a. mean coef of variation of percent germination vs. species by continent
  + 10b. mean coef of variation of germ date vs. species by continent
  + 10c. mean coef of variation of growth rate vs. species by continent
* Supplement: height vs. number of days since germination for each individual seedling, fitted with a linear fit line for each continent. The slope of this line was treated as the growth rate in all calculations. See Table 1 for species abbreviation legend.
* Tables
  + Table 2: Output of linear models of germination rate for each species (see Methods for explanation on why a generalized mixed effects model was not used). Stratification length (days), temperature (degrees Celsius), and origin were modeled as independent effects. Numerator and denominator degrees of freedom, F statistics, and the associated P-values are shown for each effect and interaction.
  + Table 3: Output of hierarchical mixed-effects model of germination date for each species. The logged days to germination was modeled as the response variable. Stratification length (days), temperature (degrees Celsius), and origin were modeled as fixed effects, while local population and individual were modeled as random effects. Numerator and denominator degrees of freedom, F statistics, and the associated P-values are shown for each effect and interaction.
  + Table 4: Output of hierarchical mixed-effects model of growth rate for each species. Stratification length (days), temperature (degrees Celsius), and origin were modeled as fixed effects, while local population and individual were modeled as random effects. Numerator and denominator degrees of freedom, F statistics, and the associated P-values are shown for each effect and interaction.
* **Model Results**
* *Germination rate*
  + General *patterns*
    - On average, 70-100% of each species germinated, except for a few populations of *Capsella bursa-pastoris* and *Plantago lanceolata* that showed much lower germination rates (~20-50%) (Figure 4). The highest average germination rate occurred in the European origin of *Plantago major* (Figure 4), while the lowest occurred in the US origin of *Capsella bursa-pastoris.* Average germination rates for most species were similar for the USA and Europe, except CAPBUR and PLAMAJ where seeds from Europe germinated significantly better (Figure 4). Temperature and origin did not alter the germination rate for any of the species (Table 2). Stratification length did not alter the germination rate for any of the species except *Plantago major* (Table 2).
  + *Plantago major*
    - Stratification length altered the germination rate for *Plantago major* (strat, F1, 16 = 6.9666, P= 0.01785) (see Table 2). All plants in the long stratification germinated, whereas germination rate was more variable in the short stratification.
* *Germination Timing* 
  + *General patterns* 
    - On average, plants took 7 to 30 days to germinate (Figure 6). Overall, CHEMAJ germinated much later than other species (22-30 days, see Figure 6), while *Dactylis glomerata* and *Taraxacum officinale* germinated the earliest (germinating in 7 days on average, see Figure 4). *Capsella bursa-pastoris* showed the largest spread in average population germination time, with some populations germinating in an average of 5 days, while others took nearly 25 days (Figure 6). Conversely, the other species showed more consistent germination time across populations (Figure 6). Temperature altered timing of germination for all species germinated, except for *Capsella bursa-pastoris* (Table 3).
  + *Capsella bursa-pastoris* 
    - Timing of germination was not altered by stratification length, temperature, nor origin (Table 3).
  + *Chelidonium majus* 
    - Days to germination was dependent overall on temperature (temp, F3, 95 =27.422, P<0.0001, see Table 3), but the exact effect of temperature depended on origin (origin × temp, F3, 95 =2.932, P=0.0375, see Table 3). Days to germination also depended on the combined effects of origin and stratification (origin × strat, F1, 95 =4.661, P=0.0334, see Table 3). *Chelidonium majus* tended to germinate later at lower temperatures across both stratification treatments and origins (Figures 7C & 7D). But response to other temperatures varied with origin (Table 3, Figures 7C & 7D). With the shorter stratification, the US origin of *Chelidonium majus* germinated earlier than the European origin (Figure 7C), while with the longer stratification germination dates were highly similar (Figure 7D).
  + *Dactylis glomerata*
    - For *Dactylis glomerata,* days to germination was dependent on temperature (temp, F3, 95 =7.5346, P<0.0001), and also on the combined effects of origin and stratification (origin × strat, F1,92 =6.377, P=0.0133, see Table 3). Overall, the US non-native population germinated earlier in the shorter stratification, but later in the longer stratification (Figures 7E & 7F). *Dactylis glomerata* germinated earlier at higher temperatures, although the long-stratified US population germinated later at the highest temperature (Figures 7E & 7F).
  + *Plantago lanceolata*
    - For *Plantago lanceolata,* days to germination was dependent overall on temperature (temp, F3, 406 =41.2581, P<.0.0001, see Table 3), with a notably later germination rate in the 11.3 degrees Celsius (Figure 7G & 7H) treatment. But dependence on temperature also varied with origin and stratification (origin × temp, F3, 406 =2.6468, P=0.0487; temp × strat, F3, 406 =2.8194, P=0.0388; origin × temp × strat, F3, 406 =6.9434, P<.00001, see Table 3). The long-stratified European origin showed a stronger response to temperature (Figure 7H).
    - Overall, stratification impacted germination date (strat, F1, 406 =17.8454, P<.0.0001, see Table 3), with longer stratification leading to a later germination (Figure 7H).
  + *Plantago major*
    - For *Plantago major*, days to germination was dependent overall on temperature (temp, F3, 131 =30.2088, P<.0.0001, see Table 3), with earlier germination at higher temperatures (Figures 7I & 7J).
    - However, days to germination also depended on the combined effects of stratification and origin (origin × strat, F1, 131 =7.1171, P<.0.0086, see Table 3). The US origin both germinated later and showed more variability in the shorter stratification (Figures 7I & 7J).
  + *Rumex crispus* 
    - For *Rumex crispus,* days to germination was dependent overall on temperature (temp, F3, 130 =9.3773, P<.0.0001) but this dependence varied with origin (origin × temp, F3, 130 =3.2384, P=0.0244, see Table 3). Further, days to germination was dependent the combined effects of stratification and origin (origin × strat, F1, 130 =36.344, P<.0.0001, see Table1). European *Rumex crispus* germinated later, but only at the short stratification (Figure 7K). The US origin at 20.7 degrees Celsius germinated the soonest, while the short-stratified European population showed the inverse response (Figures 7K & 7L).
  + *Taraxacum officinale*
    - For, *Taraxacum officinale*, days to germination was dependent overall on temperature (temp, F3, 120 =3.647, P=0.0147, see table 3) and on stratification length (strat, F1, 120 =9.439, P=.0.0026), but this latter dependence varied with origin (origin × strat, F1, 120 =36.344, P<.0.0001, see Table 3). *Taraxacum officinale* germinated earlier at mid-temperatures, except in the long-stratified European population, which showed the inverse relationship (Figures 7M & 7N). The short-stratified European origin germinated later than the US origin (Figure 7M).
* *Growth Rate*
  + Average growth rates ranged from 0.04 to 0.38 cm/day across all populations, with *Plantago major* growing the slowest and *Dactylis glomerata* growing the fastest (Figure 8). Most of the populations on average grew in the 0.05 to 0.15 cm/day range, while all of the *Dactylis glomerata* populations grew significantly faster, on average. *Dactylis glomerata* also showed the largest variability in within-population growth rate (Figure 8). The US origin growth rate did not differ significantly from that of the European origin in *Dactylis glomerata, Capsella bursa-pastoris, Plantago major, and Taraxacum officinale* (Figure 8). However, the US origin *Chelidonium majus, Plantago lanceolata, and Rumex crispus* all grew significantly faster (Figure 8).
  + *Capsella bursa-pastoris*
    - For *Capsella bursa-pastoris*, growth rate depended on temp (temp F1, 19 =26.4519, P=0.0001) and stratification (strat, F1, 19 =9.1687, P=0.0069), but the temperature dependence varied with both origin (origin × temp, F1, 19 =6.9718, P=0.0161) and stratification (origin × temp × strat, F1, 19 =6.8960, P=0.0166, see Table 4).
    - Overall there was a slight decrease in growth rate with temperature, which was much more pronounced in the US origin shorter stratification treatment (Figures 9A & 9B).
  + *Chelidonium majus* 
    - For, *Chelidonium* majus, growth rate was dependent on origin (origin, F1,2 =49.0239, P=0.0198), temperature (temp, F2,64=42.3694, P<0.0001), and stratification (strat, F1, 64=4.9397, P=0.0298), and their combined effects (temp × strat, F3, 64=7.0194, P=0.0018; origin × strat, F1,64=40.9529, P<0.0001; origin × temp × strat, F2, 64=17.5135, P<0.0001, see Table 4).
    - There is a decrease in growth rate with temperature, except in the short-stratified European *Chelidonium majus* (Figures 9C & 9D). US *Chelidonium majus* grew faster than European *Chelidonium majus* after long stratification, but the two origins were more similar, and sometimes reversed, in the short stratification (Figures 9C & 9D).
  + *Dactylis glomerata*
    - For *Dactylis glomerata*, growth rate was dependent on temperature (temp, F3, 89 =26.9803, P<.0.0001, Table 4). Overall, growth rate decreased with temperature (Figures 9E & 9F). But temperature affected the growth rates of the US and European populations differently (origin × temp, F3, 89 =3.0744, P=0.0317, Table 4). The difference was most marked at 20.7 degrees Celsius, where the long-stratified US origin grew ~ 0.15 cm/day faster than the European origin (Figure 9F).
  + *Plantago lanceolata*
    - *Plantago lanceolata* growth rate depended on temperature (temp, F3, 374 =62.5207, P<.0.0001, see Table 4). Overall, growth rate decreased with temperature (Figure 9). But this temperature-dependence varied with origin (origin × temp, F3, 374 =12.7363, P<.0.0001, see Table 4), with the US origin growing faster than the European origin at mid-temperatures and slower at extreme temperatures (Figures 9G & 9H).
  + *Plantago major*
    - *Plantago major* growth rate was dependent on temperature (temp, F3,129=92.3502, P<0.0001), and stratification (strat, F1,129=111.8433, P<0.0001), and these effects were dependent on each other (temp × strat, F3,129=44.8222, P<0.0001) and origin (origin × temp, F3,129=3.3338, P=0.0216; temp × strat, F3,129=44.8222, P<0.0001, see Table 4). Long-stratified *Plantago major* grew more slowly at higher temperatures, while the growth rate was more uniform at shorter stratification (Figures 9I & 9J). The US and European populations had similar growth rates, except at the lowest temperature (Figures 9I & 9J).
  + *Rumex crispus* 
    - *Rumex crispus* growth rate depended on temperature (temp F3, 125 =141.5037, P<0.0001, see Table 4), with growth rate overall decreasing with temperature (Figures 9K & 9L). Growth rate also depended on stratification (strat, F1, 125 =5.2366, P=0.0238), and the combined effects of temperature and stratification (temp × strat, F3, 125 =4.7559, P=0.0036), and their combined effects with origin (origin × temp, F3, 125 =17.38065, P<0.0001; origin × strat, F1, 125 =17.38065, P<0.0001; origin × temp × strat, F3, 125 =12.1615, P<0.0001, see Table 4). The US origin growth rate did not depend on stratification, while the European growth rate showed less dependence on temperature in the short stratification treatment (Figures 9K & 9L). The US origin growth rate also showed more uniform response to the different temperature treatments, while the European origin showed a much weaker response at the extreme temperatures (Figures 9K & 9L)
  + *Taraxacum officinale*
    - *Taraxacum officinale* growth rate depended on temperature (temp F3, 115 =11.9840, P<0.0001, see Table 4). Overall, growth rate was higher at lower temperature (Figures 9M & 9N). Growth rate also depended on stratification (strat, F1, 115 =16.4810, P=0.0001), with more variability in growth rate at long stratification (Figures (9M & 9N). *Taraxacum officinale* growth rate also depended on the combined effects of temperature and stratification (temp × strat, F3, 115 =4. 3.2202, P=0.0261, see Table 4), with faster growth in the shorter stratification treatment, except for the plants grown at 11.3 degrees Celsius (Figures 9M & 9N). Growth rate further depended on the combination of all three effects (origin × temp × strat, F1, 115 =17.38065, P=0.0255, see Table 4)—in the short stratification treatment, the growth rate of the European *Taraxacum officinale* was unaffected by temperature, while the US growth rate decreased at mid-temperatures (Figures 9M & 9N). However, in the long stratification treatment, both *Taraxacum officinale* origins exhibited decreases in temperature, although the European origin showed a sharper decrease at 20.7 degrees Celsius to a slower growth rate than the US origin.
* **Coefficient of variation ( CV) results** 
  + Germination rate
    - The mean CV for germination rate was not significantly different between the origins for *Chelidonium majus, Dactylis glomerata, Plantago lanceolata, Rumex crispus, and Taraxacum officinale* (Figure 10A)*.* However, the CVs for *Capsella bursa-pastoris* and *Plantago major* were significantly higher in the US origin (Figure 10A).
  + Germination timing
    - The mean CV for days to germination was not significantly different between the origins for *Plantago major* (Figure 10B). However, the CVs were significantly higher in the US origin for *Capsella bursa-pastoris, Plantago lanceolata, Rumex Crispus,* and *Taraxacum officinale*, while the CV’s were significantly higher in the European origin for *Chelidonium majus,* and *Dactylis glomerata* (Figure 10B).
  + Growth rate
    - The mean CV for growth rate was not significantly different between the origins for *Plantago lanceolata* (Figure 10C). However, the CVs for *Capsella bursa-pastoris,* and *Plantago major* were significantly higher in the US origin, while the CV’s were higher in the European origin for *Chelidonium majus, Dactylis glomerata, Rumex Crispus,* and *Taraxacum officinale.*