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AN EXAMINATION OF REPRODUCTIVE PHENOLOGY WITH IMPLICATIONS FOR UNDERSTANDING CLIMATE CHANGE EFFECTS

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✦ ABSTRACT

Climate change has impacted ecological systems in a variety of ways, leading to advancement in spring events, shifts in species distributions, and changes in phenology (the timing of life history events) for many plants and animals. Earlier spring temperatures have been correlated with earlier emergence of a number of butterfly species in Europe. It is possible that changes in the spring could also influence the timing of events throughout the season.

The Clodius Parnassian (*Parnassius clodius*) butterfly has one flight per year that averages 3 weeks in length. The males emerge first, followed shortly by the females. Reproductive success of these butterflies depends on the timing of emergence and mating events. A disturbance in the timing of emergence between males and females could cause an incomplete temporal overlap between the sexes, leading to reproductive asynchrony. Reproductive asynchrony occurs when males and females within a population do not overlap completely in time, and it can significantly affect population dynamics of species with narrowly defined breeding periods, such as univoltine butterflies. Our research examined how climate change may influence flight time and mating success in *Parnassius clodius* butterflies. A mark-recapture study to assess timing of emergence and mating success was performed in Grand Teton National Park. Six plots were surveyed daily for *Parnassius clodius* butterflies using mark recapture techniques during the annual flight period from late June until mid-July 2009. Each captured butterfly was marked with a permanent marker on both of its hindwings prior to release. The sex and wing condition of each butterfly was determined and recorded at time of capture.

A total of 838 butterflies were marked during the 2009 flight period, with a recapture rate of 26%. Preliminary examination of the data reveals the expected pattern of male emergence prior to female emergence. The emergence times appear consistent with other survey years. We also observed a small number of unmated females at the end of the season. Further data analysis needs to be performed before any additional conclusions can be made. This study provides a baseline understanding of climatic and phenological trends in an effort to understand how gender-specific emergence times and mating status of a common species of butterfly (*Parnassius clodius*) may be affected by climatic changes.

✦ INTRODUCTION

Global climatic patterns have shown increased temperatures since the 1970s (Intergovernmental Panel on Climate Change 2007). Atmosphere-Ocean General Circulation Model (AOGCM) simulations for the Intergovernmental Panel on Climate Change (IPCC) estimate a 1.4°–5.8°Celsius temperature increase during the period from 1990–2100 (Cubasch et al. 2001, Notaro et al. 2006). It is expected that warming will be increased over land surfaces particularly over the northern regions of North America and Asia (Cubasch et al. 2001, Notaro et al. 2006). During the period from

2003 – 2007, the western United States had an average increase of 3°Celsius when compared to the 20th century average (Saunder et al. 2008). The largest changes in temperatures have been recorded in the spring and winter (Karl et al. 1996, Hengeveld and Whitewood 2005, Field et al. 2007). In the United States and Canada, the growing season has increased in length an average of 2 days per decade since 1950 with most of the increase resulting from earlier spring warming (Bonsal et al. 2001, Easterling et al. 2000, Bonsal and Prowse 2003, Field et al. 2007). Advancement of spring events has been documented in all continents except the Antarctic (Parmesan 2006).

These changes will have impacts on ecological communities at a variety of levels, from the individual to the population, community and ecosystem. Quantifying these responses, however, is not always easy, so scientists must carefully select study organisms that are good indicators of such changes. Here we began our first field season of a project that will examine how climate change may be influencing emergence times and reproductive success of Apollo butterflies (*Parnassius clodius*) in Grand Teton National Park. This species is relatively common, easy to mark and handle, and females acquire a very obvious mating plug that allows us to determine whether they have been mated.

Many long-term studies have shown that climate change has altered biological systems and is correlated with changes in phenological patterns of a variety of species (Bradley et al. 1999, Gibbs and Breisch 2001, Parmesan and Yohe 2003, Root et al. 2003, Menzel and Dose 2005, Parmesan 2006). The phenology of an organism refers to its response to seasonal and climatic changes in the environment. Phenology is tightly linked to environmental conditions and often evolved to maximize fitness (Futuyma 1998, Stenseth and Mysterud 2002). Therefore, phenological changes are often used to explore the effects of climate change on population and community dynamics (Thorne et al. 2006).

Phenological changes can also lead to population-level challenges in species that show gender-specific responses to climate in terms of emergence time or sex determination, and these species can be particularly good indicators of climate change. Both reproductive asynchrony and protandry are phenological events that can be influenced by climate change. Reproductive asynchrony occurs when there is an incomplete temporal overlap between males and females within a population, such that individuals are reproductively active for only a portion of the breeding period (Calabrese and Fagan 2004, Calbrese et al. 2008). This phenomenon is usually present in strongly seasonal species with a defined breeding period such as univoltine butterflies which have only one emergence period per season (Calabrese and Fagan 2004, Calbrese et al. 2008).

Protandry, a phenological trait exhibited in many insect species, where males emerge before females, is often linked with asynchrony (Wiklund et al. 1977, Zijlstr et al. 2002, Calabrese et al. 2008). Mathematical models have shown that male mating success selects for protandry in univoltine species that mate soon after eclosion (emergence of an adult insect from its pupal case) (Wiklund and Faberström 1977, Boggs 2003). The emergence and peak of the male population before that of the female population not only increases chances of finding a mate but also ensures that females spend less time unmated (Faberström and Wiklund 1982, Boggs et al. 2003).

Butterflies are useful indicators of climate change because they are extremely sensitive to environmental conditions such as temperature (Dennis 1993). Emergence dates show a high correlation with spring temperatures. Earlier spring warming has been correlated with earlier emergence of a number of butterfly species in Europe (Roy and Sparks 2000, Stefanescu et al. 2003). In addition, Forister and Shapiro (2003) reported that 70% of 23 butterfly species in central California advanced their first flight date by an average of 24 days over 31 years.

In univoltine butterfly species that have evolved protandry, reproductive success depends on the timing of emergence and mating events. If the earlier advancement of spring events does not affect males and females uniformly, a breakdown in evolved reproductive timing may result. Therefore, studies to understand the timing of emergence and mating will be useful in further understanding how climate change may affect insect species.

The objectives of this research included examining and comparing the emergence times between male and female *Parnassius clodius* butterflies and determining the number of unmated females at the end of the flight season. More specifically, because males emerge first, we expected that we would capture more males than females at the beginning of the flight season. As the season progressed, we expected more females would emerge and the proportion of males to females would change. During the peak flight period, we expected that mated females would outnumber unmated females.

✦ METHODS

Six plots were sampled in 2009 in a relatively flat sagebrush meadow located in Grand Teton National Park. Plots were 50 x 50 meters in size and approximately 200 meters apart. We conducted mark–recapture surveys during the annual flight period of 2009. The plots were randomly sampled for the presence of Clodius Parnassian (*Parnassius Clodius*) beginning June 24th until July 12th. Surveys began shortly after the first butterflies emerged and were terminated when less than 5 butterflies were seen in the plots. During a survey 2 people walked within a plot to survey butterflies for a total of 20 minutes. Surveys were limited to times between 10:00 and 17:00 hours, and when the temperature was above 21° C, wind was <16kmh^{-1}, and the sun was not obscured by clouds. *Parnassius clodius* butterflies were captured using butterfly nets and placed in glassine envelopes until the end of the survey. Unmarked butterflies were marked with a permanent marker on the ventral side of each hindwing, indicating the day and plot in which it was caught. Day and plot information for previously marked butterflies was recorded at each recapture. The sex of each butterfly was determined based on external morphological differences and females were examined for mating status by the presence or absence of a sphragus (a waxy structure deposited by the male during mating that prevents future matings). Wing condition was also recorded for all captured butterflies. All butterflies were released from the center of the plot after information was recorded.

✦ RESULTS AND DISCUSSION

A total of 838 butterflies were marked during the flight period with a recapture rate of 26%. The seasonal emergence pattern by sex is shown in Figure 1. Male butterflies emerged approximately June 23rd and were first marked on June 24th. Females were first captured and marked on June 25th. The peak flight time for males was July 2nd. Females had two abundance peaks, one on July 5th and a second on July 10th. The emergence times are consistent with other survey years. The ratio of males to females was close to 23 to 1 at the start of the flight period and close to 1 to 1 ratio at the end of the flight period. Unmated females were first observed on June 27th. The ratio of mated to unmated females was 1 to 1 when the first unmated females were captured. However, as the flight period progressed, mated females outnumbered unmated females as much as 22 to 1 during peak flight time. The highest numbers of unmated females were found on June 9th, which was 1 day before the second peak of female numbers.

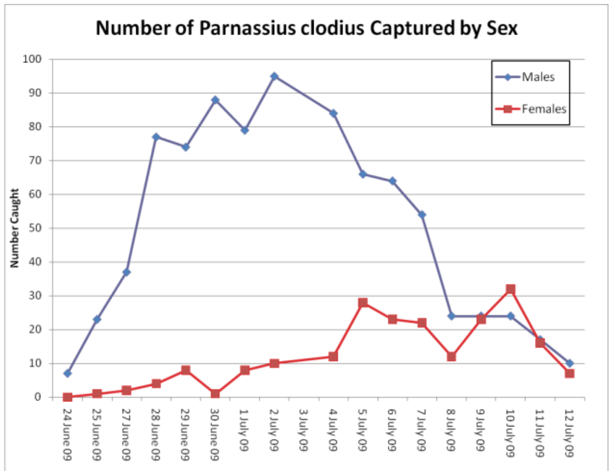

Figure 1. Emergence of *Parnassius clodius* over the flight season in 2009 within meadows near Pilgrim Creek, WY.

✦ CONCLUSIONS

Climate change has already been noted in many regions throughout the world. Understanding the how species interact and utilizing that knowledge to predict changes will be important for understanding climate change. The results from this study confirm the asynchrony between male and female emergence times. The information gathered from the study of female mating status provides a baseline for further study of the reproductive asynchrony. Additional research into the dynamics of the system is needed to better understand the degree of synchrony in this location as well as other locations and to understand the potential ways that these relationships might be modified under changing climatic conditions.

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