

Rocky Mountains (Figure 1, Sherwood 2013). We used a replicated block design of snow removal (SR) and passive heating (H+), both treatments (SR and H+) and a control (CT) to examine the effects of temperature, snow removal and their potential interactions on soil conditions, plant growth, and insect responses. In 2014 we added a new dimension: assessing how snow removal and warming affect nectar resources for pollinators. Our hypothesis was that reduced soil moisture from reduced snowpack and passive heating would be correlated with lower nectar volume and/or sugar content in nectar plants.

✦ METHODS

Study organisms and study site

The study area for this study is a sagebrush (*Artemisia* sp.) meadow at an elevation of 2100 meters. This area has relatively flat, homogeneous topography and is located in Grand Teton National Park, WY. The meadow is approximately 2 x 0.5 km in size (Auckland *et al.* 2004) and is just south of the University of Wyoming-National Park Service Research Station, where our research team is housed during the field season. For this project, we monitored *Balsamorhiza sagitata* (Arrowleaf Balsamroot, below left) and *Eriogonum umbellatum* (Wild Buckwheat, below right). These two nectar resources are particularly valuable to the butterfly *Parnassius clodius* (butterfly in photo at right) found within this system.



Field methods

The experimental design includes three replicated blocks of four 2.5 x 2.5 m plots with the following treatments: snow removal (SR), passive heating (H+), both treatments (SR and H+) and control (CT). Each plot is separated by 5 m and is laid out in a regular pattern within the meadow. The plots were set up in 2010, with landscape edging buried to delineate plot edges.

Snow is removed manually using shovels at the end of April/early May. Assuming 53 cm/yr of precipitation (Shaw 1958), mostly as snow, with a spring snowpack that is about 50% water by volume (California Department of Water Resources [n.d.]), removing 50 cm of the snowpack (i.e., all snow still present in early May) can reduce the annual precipitation by approximately one half. As we have developed these techniques, we have determined that snow depth should be maintained at ~2 cm in treatment plots to minimize the possibility of vegetation damage. New or wind-driven snow is removed when present after the initial snow removal. Snow depth in control plots is also measured and recorded during the sampling period.

We utilized a louvered Open-Sided Chamber (OSC, Figure 1) to warm our plots, placed on the site when snow is removed in late April/early May and left there through the growing season. OSC's passively increase the downwelling infrared (longwave, or thermal) radiation to plant and soil surfaces, thereby increasing minimum nighttime temperatures by several degrees Celsius (Germino and Smith 1999). There are a variety of both active (e.g., infrared lamps or heating cables) and passive (e.g., open-top chambers, shelters, or covers) methods available for creating warming conditions (Kennedy 1994, Convey and Wynn-Williams 2002, Bokhurst, et al. 2008). Each method has advantages and disadvantages for changing light or moisture regimes or altering of wind patterns or atmospheric exposure (Beier et al. 2004), and most of these approaches have been used to increase maximum daily temperatures (i.e., Kennedy 1994, Convey and Wynn-Williams 2002, Bokhurst, et al. 2008). It is important to evaluate ways to experimentally simulate increased *minimum* temperatures given that the daily minimum temperatures are increasing faster than daily maximum temperatures (Kukla et al. 1994, Alward et al. 1999).

Temperature and soil moisture are measured and recorded at 25 cm depth using soil moisture meters buried in the soil (Sherwood 2013). Debinski (unpublished data) showed that snow removal in early May can affect soil moisture at 25 cm depth through the growing season. Dataloggers record daily at 12:00 hrs through the summer.

Extracting nectar

During the flowering season, nectar was collected from each plant within the plot as it reached peak flowering time. We extracted the nectar using

microcapillary pipettes, placed into the flower where the nectar pools. Once the nectar was extracted from the flower, we measured the length (in mm) of nectar within the tube, the size of the microcapillary pipet, and the temperature and relative humidity. We used a refractometer (with a Brix scale). Because buckwheat has very small flowers, we pooled samples from five flowers.

Calculating nectar volume

Nectar volume was calculated using the following equation:

$$\text{microcap size } (\mu\text{L}) * \frac{\text{mm of nectar in pipet}}{\text{mm length of pipet}} = \text{Volume of nectar } (\mu\text{L})$$

Determining sugar concentration

We converted the percent sucrose (Brix value) to concentration of sugar (mg/mL) (Kearns and Inouye 1993). Nectar sugar concentration is calculated using the following equation:

$$\text{Nectar volume } (\mu\text{L}) * \text{concentration of sugar } \left(\frac{\text{mg}}{\text{mL}}\right) * \frac{1\text{mL}}{1000\mu\text{L}} = \text{Amount of Sugar}$$

◆ RESULTS

We compared both nectar volume and sugar content of each plant species relative to treatment (Tables 1 and 2). Preliminary analysis show that for *Eriogonum umbellatum* nectar volume was lower in the heating compared to either the control or snow removal and that heating and snow removal was also lower than snow removal only. The sugar amount did not show much variation among treatments. For *Balsamorhiza sagittata* there were no differences among treatments in the nectar volume, but there were differences in the sugar amount. Preliminary results show that the control was lower in sugar volume than the heating + snow removal.

◆ CONCLUSIONS

These data show that there could be changes in nectar resources associated with warming and/or reduced snowpack. They also show that the responses could vary among plant species. Such changes could have important implications for the pollinator community in Grand Teton National Park.

Table 1. 2014 GTNP nectar results: Sulphur Buckwheat (*Eriogonum umbellatum*)

Treatment	Nectar Volume (μL)		Sugar Amount (mg)	
	Average	Standard Deviation	Average	Standard Deviation
Control (n = 54)	0.68	0.46	344.66	169.07
Heating (n = 60)	0.52	0.22	335.90	131.16
Snow Removal (n = 57)	0.75	0.57	401.25	323.42
Heating + Snow Removal (n = 57)	0.57	0.29	353.02	170.11

Table 2. 2014 GTNP nectar results: Arrow-leaved Balsamorhiza (*Balsamorhiza sagittata*)

Treatment	Nectar Volume (μL)		Sugar Amount (mg)	
	Average	Standard Deviation	Average	Standard Deviation
Control (n = 23)	0.32	0.17	163.15	65.88
Heating (n = 20)	0.33	0.13	191.71	80.80
Snow Removal (n = 28)	0.36	0.28	164.48	160.58
Heating + Snow Removal (n = 19)	0.37	0.21	225.73	107.04

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