Impact of ambient temperature, precipitation and seven years of experimental warming and nutrient addition on fruit production in an alpine heath and meadow community

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Abstract

Global change is causing changes in temperature, precipitation, and nutrient availability. Alpine and polar regions are predicted to be among the most vulnerable for these changes. We applied a seven-year factorial experiment with warming and nutrient addition in two alpine vegetation communities. We analyzed relationship between fruit production and monthly mean, max and min temperatures during the fall of the pre-fruiting year, fruiting summer, whole fruit production period, and effects of summer and winter precipitation on fruit production. Nutrient addition and combined nutrient addition and warming increased total fruit production, and fruit production of graminoids in the later years in the Heath and Meadow and had a positive effect on forbs in the Meadow. In contrast fruit production of evergreen shrubs were negative affected by all treatments in the Meadow and Heath, while fruit production of deciduous shrubs was negatively affected in the Meadow. Minimum and mean temperatures were more important than max temperatures, and max temperatures of the fall before flowering was more important than max temperature during the flowering year. Winter precipitation had significant effect on total fruit production, fruit production of deciduous shrubs and forbs in the Heath, and on evergreen shrubs and forbs in the Meadow. Increased nutrient availability increased fruit production over time in contrasting high alpine plant communities, while experimental warming had no, or negative effect. Additionally, the results indicate that warmer summers may have limited impact on fruit production of high alpine plants. Instead, max temperatures during the fall before the fruiting year, and minimum temperatures may be more important.

Keywords: Arctic; climate change; cold spells; plant reproduction; fruit production; ITEX; Tundra

1. Introduction

Alpine and polar regions are foreseen to be highly vulnerable to climate change with increased climatic variability and climatic events in the future which may affect plant reproductive success. Reproductive success of plants in cold regions can be affected by several environmental factors. Similar to the advancement of flowering of plants in temperate regions in response to climate change (Berg et al. 2019; Renner et al. 2021), timing of flowering of plants in high alpine and polar regions are also affected by the temperature/climate (Miller-Rushing and Inouye 2009; Panchen and Gorelick 2015; Legault and Cusa 2015; Hall et al. 2018), flower production (Inouye et al. 2003; Kudo and Hirao 2006; Liu et al. 2012), seeds and seedlings (Bernareggi et al. 2015; Briceño et al. 2015), and fruit production (Alatalo et al. 2021). The responses can be affected by growing degree days (GDD), thawing degree days (TDD), min and max temperatures (White 1979; Inouye et al. 2003; Hollister et al. 2005; Kudo and Hirao 2006; Legault and Cusa 2015). Temperature can also affect bud formation both during the actual flowering year (many forbs and graminoids) and in the "previous fall" for plants that initiate their flower buds the year before actual flowering (many deciduous and evergreen shrubs) (Molau et al. 2005; Alatalo et al. 2021). With minimum temperature often being more important than max temperatures (Bergman et al. 1996; Alatalo et al. 2021), as buds and flowers can be vulnerable to frost, and pollinators are less active during cold periods (Bergman et al. 1996; Inouye 2008; Wheeler et al. 2016). In addition, changes in plant phenology due to warmer springs may cause disruption of plant-pollinator interactions (Høye et al. 2013; Kudo and Ida 2013; Kudo 2014). Both increased winter and summer precipitation have been shown to have negative effect reproductive success of plants (Phoenix et al. 2001; Bjorkman et al. 2015; Lawson and Rands 2019; Alatalo et al. 2021). The effect of the different climate parameters on plant reproduction can also vary among plant functional groups and the timing when it occurs (Molau 1993; Alatalo et al. 2021). In addition, reproductive success of flowering plants in cold regions can be limited by relatively few pollinators and highly variable weather conditions (Alatalo and Molau 2001; Lundemo and Totland 2007; Peng et al. 2014; Straka and Starzomski 2015). Flies which are important as pollinators in cold areas (Bergman et al. 1996), have been shown to decrease in abundance and richness with accompanying warming during the last decades in Greenland (Loboda et al. 2018). Vegetation in high alpine and polar regions are also often nutrient limited (Chapin et al. 1986; Shaver and Kummerow 1992), and this can also affect plant reproduction (Wookey et al. 1995; Moulton and Gough 2011; Alatalo and Little 2014). Therefore, anthropogenic nutrient depositions and increased mineralization due to climate change will likely also affect plant communities (Neftel et al. 1985; Cleve et al. 1990; Grandy et al. 2008; Clark et al. 2013).

Experimental studies focusing on different aspects of global change impact on plant reproduction in alpine and polar regions have found contrasting effects from experimental warming (Liu et al. 2012; Alatalo and Little 2014; Cui et al. 2017; Alatalo et al. 2021). Studies have focused on phenology (Wookey et al. 1993; Alatalo and Totland 1997; Totland and Alatalo 2002; Aerts et al. 2004; Mallik et al. 2011), flower production (Semenchuk et al. 2013), seed production (Wookey et al. 1993; Alatalo and Totland 1997; Cui et al. 2017; Zhang et al. 2019), and fruit production (Wookey et al. 1993; Alatalo and Little 2014; Alatalo et al. 2021). Studies on the effect of experimental nutrient addition have focused on seed/fruit production (Wookey et al. 1993, 1995; Gough et al. 2015; Lavrenov et al. 2017), phenology (Wookey et al. 1995; Zhang et al. 2014; Xi et al. 2015), reproductive allocation/effort (Wookey et al. 1995; Moulton and Gough 2011; Petraglia et al. 2013; Zhang et al. 2014), seed germination/seedling mortality (Milbau et al. 2017).

This is study is part of a set of different climate change experiment at the Latnjajaure field station. We have previously reported the impact of warming and nutrient addition on growth, abundance, diversity and richness of plants (Alatalo et al. 2014, 2015). In the current study we focus on the impact of seven years of warming and nutrient addition, and ambient climate parameters, on the reproductive success (in terms of fruit set) in two contrasting alpine plant communities, a nutrient and species poor heath (Alatalo et al. 2015, 2017), and a meadow with relatively higher species richness and nutrient content (Alatalo et al. 2014, 2017). We hypothesize 1) that both warming and nutrient addition will have a positive impact on fruit set of total and all plant functional groups (graminoids, forbs, deciduous and evergreen shrubs). 2) Ambient temperature during the fall of the previous year and the current year will be positively correlated with fruit production of deciduous and evergreen shrubs. 3). Ambient temperature during the current year will be positively correlated with fruit production of graminoids and forbs. 4). Minimum temperatures will be more important than max temperatures for fruit set. 5) Both winter and summer precipitation will be negatively correlated with fruit production.

2. Methods

2.1. Study area

Latnjajaure field station is located above treeline at 1000 m elevation in the valley of Latnjavagge (68°21´N, 18°29´E), near Abisko, northern Sweden. The climate is classified as sub-arctic, with cool summers and relatively mild winters, the valley is snow covered for most of the year. Mean annual temperature ranged between -2.89C (1995) and -1.56C (2000), with winter minimum ranging between -21.7C (1997) and -28.8C (1999). Mean annual precipitation ranged between 607mm (1996) – 877mm (2000). July is normally the warmed month, with mean temperatures ranging between 5.93C (1995) and 9.92C (1997). Physical conditions in the valley soils vary from dry to wet, and from acidic to base-rich, with an associated variation in plant communities (Molau and Alatalo 1998; Lindblad et al. 2006; Björk et al. 2007; Alatalo et al. 2014, 2017). The meadow community has a well-developed vegetation cover, dominated by *Carex vaginata*, *Carex bigelowii*, *Festuca ovina*, *Salix reticulata*, *Salix polaris*, *Cassiope tetragona*, *Bistorta vivipara* and *Thalictrum alpinum* (Molau and Alatalo 1998; Alatalo et al. 2014). The more sparsely vegetated heath community is dominated by *Betula nana*, *Salix herbacea* and *Calamagrostis lapponica* (Molau and Alatalo 1998; Alatalo et al. 2015).

2.2. Experimental design and measurements

We randomly assigned 20 1 m^2 plots in the heath and meadow to treatments, control (C, 8 plots), nutrient addition (N, 4 plots), warming (W, 4 plots) by Open Top Chambers (OTCs), and combined warming and nutrient addition (WN, 4 plots) (Molau and Alatalo 1998). The OTCs increased the temperature by 1.5 to 3C compared to control plots experiencing ambient temperature (Molau and Alatalo 1998). Nutrient addition was applied by dissolving 5 g of nitrogen (as NH_4NO_3) and 5g of phosphorus (P_2O_5) in 10 l of meltwater which was then applied for each plot (1 m^2) (Molau and Alatalo 1998). The OTCs were left on the plots for the whole period of the study.

To assess reproductive success, we counted fruit production of all plant species in the plots at the end of each vegetation season (late August, 1994-2000). Fruit production, or infructescences (as in graminoids), is a good proxy for reproductive success as it is correlated with seed production (Alatalo and Molau 2001). In addition to total fruit production, we grouped fruit production into functional groups (evergreen shrubs, graminoids, deciduous shrubs, forbs) (Chapin et al. 1996).

2.3. Statistical analysis

To check the significant differences among treatments, years, vegetation and their interactions in fruit production for the four plant functional groups (graminoids, forbs, deciduous and evergreen shrubs) and total fruit production (all plant functional groups combined), General linear model for factorial experiment was used. Analysis of variance of fruit production was performed, the additive model for analysis of variance was:

$$Xij = \mu + Y + T + V + (Y \times T) + (Y \times V) + (T \times V) + (Y \times T \times V) + \mathcal{E}ij$$

where Xij is the fruit production. μ is the grand mean of all recorded observations. Y is the single factor effect of year on fruit production. T is the single factor effect of treatment on fruit production. V is the single factor effect of vegetation on fruit production. While (YxT), (YxV), and (TxV) are the first order interactions between two factors. The second order interaction is represented as (YxTxV). Ɛij represents the experimental error. The formulated equation explains the sources of variation that can be observed in the fruit production when conducting statistical analysis. Bonferroni Pairwise Comparisons test was used to compare between each two means.The statistics software package Minitab (Minitab 17, 2010, Computer software, State College, PA: Minitab) was used to obtain ANOVA tables and means comparisons.

To analyse the relationship between fruit production and ambient climate parameters we used Pearson correlation coefficient in MS-Excel (Microsoft). Precipitation, maximum temperature, minimum temperature and mean temperature were considered for ambient climate. The fruiting process in vegetation govern by the climatic conditions prior to the fruiting period (the fall before the year when the fruit is produced), current period (the year the fruit is produced) along with the climate regime during the period of whole fruiting process. Therefore, the period has been divided into three categories as pre (prior fruiting period i.e. August, September and October of the year before fruit production); current (current fruiting period i.e. May, June, July and August) and total (whole period of fruiting i.e. August, September, October, May, June and July). Means of all four climatic parameters were considered for the three periods. Association (correlation) was estimated between all climatic parameters for all the three periods with fruit production of the four plant functional groups (graminoids, forbs, deciduous and evergreen shrubs) and total fruit production (all plant functional groups combined). The significance of the correlation was adjudged at 5% level of significance by standard protocol i.e. t-test.

3. Results

3.1. Effect of experimental warming and nutrient addition on total fruit production

There was a significant impact by year, treatment, and vegetation community, and a significant interaction between year and treatment, and between year and vegetation, on total fruit production (Table 1, Figure 1). With total fruit production varying significantly among years, treatments, and vegetation communities (Appendix S1, see the Supplementary Data with this article). In general, nutrient addition and the combined warming and nutrient addition increased total fruit production in the later years of the experiment (year six and seven) in both communities (Fig. 1), and total fruit production being higher in the Meadow compared to the Heath (Fig. 1, Appendix S1). Similarly, total fruit production in control plots in both the Heath and Meadow varied over time, peaking in years 4-6 of the experiment. In contrast, experimental warming alone tended to decrease total fruit production in both communities (Fig. 1).

3.2. Effect of experimental warming and nutrient addition on fruit production by plant functional groups

3.2.1. Fruit production of graminoids

Fruit production of graminoids was significantly affected by year and treatment (Table 1). There were significant interactions between year and treatment, and treatment and vegetation, for graminoids (Table 1, Appendix S2, see the Supplementary Data with this article). Nutrient addition and combined nutrient addition and warming dramatically increased fruit production of graminoids in both the heath and meadow community. With the positive effect of nutrient addition and the combined warming and nutrient addition increasing over time in both communities (Fig. 2). The increase of fruit production in the Heath was mainly driven by a large increase of *Callamagrostis lapponica*.

3.2.2. Fruit production of forbs

There was significant effect of year, treatment, and vegetation on fruit production of forbs (Table 1). There was a significant interaction between year and vegetation, and treatment and vegetation, for forbs (Table 1, with the fruit production varying considerably both between years, treatments, and vegetation (Fig. 2, Appendix S3, see the Supplementary Data with this article). Nutrient addition and combined nutrient addition and warming tending to have a positive effect on forbs in the Meadow from year three onwards (but not in the Heath) (Fig. 2). Warming had no effect on fruit production of forbs in either plant community (Fig. 2).

3.2.3. Fruit production of evergreen shrubs

There was significant effect of year, treatment, and vegetation on fruit production of evergreen shrubs (Table 1). There were significant interactions between year and treatment, and year and vegetation for evergreen shrubs (Table 1), with fruit production varying considerably between years, treatments, and vegetation communities (Fig. 3, Appendix S4, see the Supplementary Data with this article). Specifically, fruit production was highest in the control plots experiencing ambient conditions, with warming, nutrient addition, and the combined warming and nutrient addition treatments all having a negative effect on fruit production in both the Meadow and Heath (Fig 3).

3.2.4. Fruit production of deciduous shrubs

There was significant effect of year, treatment, vegetation, and a significant interaction between year and vegetation on the fruit production of deciduous shrubs (Table 1). In the Heath, while the impact of treatments varied greatly among years, fruit production of deciduous shrubs tended to be highest in control and warming plots, (Fig. 3, Appendix S5, see the Supplementary Data with this article). In contrast, in the Meadow, fruit production of deciduous shrubs tended to be highest in the control plots and in the plots receiving nutrient addition alone (Fig. 3, Appendix S5, see the Supplementary Data with this article).

3.3. Effect of ambient climate parameters on fruit production

3.3.1. Meadow

The correlation analysis on the relationships between ambient climatic parameters with fruit production in the meadow showed that minimum and mean temperatures were more important than max temperatures**.** The fruit production of deciduous shrubs in the meadow was negatively correlated with current precipitation, temperature specifically pre-maximum, total maximum, current minimum temperature, however, total minimum and total mean temperature was positively related with seed production in deciduous shrubs. The fruit production of evergreen shrubs in the meadow was having a differential directional relationship with climatic parameters. In this, only pre-max temperature were negatively related with fruit production of evergreen shrubs in the meadow, however, temperature regimes as pre-minimum, current minimum, total minimum, pre-mean, current mean and total mean temperature along with pre-maximum temperature were positively related with fruit production of evergreen shrubs. The fruit production of graminoid in the meadow was increasing with increase in various temperature regimes as pre-minimum, current minimum, total minimum, pre-mean, current mean and total mean temperature, however, it decreased with increase in pre-maximum temperature. All the three regimes of minimum temperature and mean temperature were positively influencing the fruit production of forbs except current minimum temperature. Total functional fruit production in the meadow was positively related with all the three regimes of minimum temperature and mean temperature except current minimum temperature, however pre-maximum temperature was negatively related with total fruit production (Table 2A).

3.3.2. Heath

The fruit production process in the heath has a differential regulated by the various climatic parameters. The total fruit production was positively governed by the three regimes of precipitation, minimum temperature and mean temperature except the current precipitation. The pre-maximum temperature governs the negative relationship with total fruit production in the heath. The fruit production of deciduous shrubs in the heath was governed by all the climatic regimes except the current precipitation and total maximum temperature. The climatic parameters role on fruit production of evergreen shrubs in the heath was invariant except the negative role of pre-maximum temperature. Fruit production of graminoid in the heath was positively influenced by all the three regimes of minimum and mean temperature, except the current minimum temperature. Fruit production of forbs in the heath was positively influenced by current and total minimum and mean temperature regimes and negatively related with pre-precipitation (Table 2 B).

4. Discussion

Our results showed that fruit production was increased in both vegetation types after seven years of experimental warming. Nutrient addition treatment in the meadow and combined nutriend addition and warming in the heath led to the highest fruit production. Therefore, our proposed hypothesis was partially true. However, after four years, in both vegetation types, warming treatment led to a dramatic decrease in fruit production comparing to the control and the other treatments. On the other hand, nutrient addition increased fruit production in both vegetation types. This finding revealed the importance of the other factor (nutrient availability) for successful fruit production in alpine plants.

While we did not monitor the phenological period in the study, changing the phenological period due to warming is one of the critical impacts of climate change (Cleland et al. 2007; Oberbauer et al. 2013; Scranton and Amarasekare 2017). While growing season for plants has increased in the alps (earlier and longer), shorter and delayed growing season has been reported from central Tibet (Oberbauer et al. 2013). Thus, as a result of decreased fruit production period late-flowering species will be more susceptible to warming (Zhu et al. 2016), while prolonged growing season can have a positive effect on reproduction success (Briceño et al. 2015). In addition, plants may exhibit intraspecific variation across their range in their responses to climate and warming (Love and Mazer 2021).

Here, we observed that major changes occurred after four years of the experiment. Thus, as Klady et al. (2011) suggested, our finding highlighted the importance of performing long-term studies on the effects of different climate change factors on reproductive success of plants. Comparing the two vegetation types, after four years, we observed more drastic responses of heath community than meadow vegetation. Previous studies on species composition and diversity also suggest that the heath vegetation was more susceptible to warming and nutrient addition than the meadow (Alatalo et al. 2014, 2015). The different properties of a vegetation type (e.g., soil factors) modifies its response to climate change impacts (Oberbauer et al. 2013; Alatalo et al. 2015).

Our results revealed vegetation (site-) specific response of different functional types to climate variables. The differential response of functional types to climatic variables and climate change will likely reshape plant community structure in alpine regions (CaraDonna et al. 2014). This support previous studies that have reported reproductive responses to climate change to differ among plant species/functional groups (Klady et al. 2011; Briceño et al. 2015; Carbognani et al. 2016). Graminoids were the only functional group that had a similar response to the treatments at heath and meadow. We observed an increased fruit production of graminoids in both vegetations in response to nutrient addition and combined nutrient addition and warming, while warming alone tended to have a negative effect. This reflects the responses in terms of abundance of graminoids to the specific treatments in both communities (Alatalo et al. 2014, 2015). Seed production increase in graminoids in a warming experiment was also reported from high-arctic Canada (Klady et al. 2011). OTCs that are used in climate change studies could potentially limit pollen availability (Adamson and Iler 2021; Alatalo et al. 2021). For example, OTCs decreased visitation rates of pollinators two species with 92% in a *Delphinium nuttallianum* and by 85% in *Potentilla pulcherrima* in Rocky Mountains. This caused a large decline in pollen grains on stigmas in *Delphinium* but not for *Potentilla* (that is autogamous) (Adamson and Iler 2021). Thus, the increased seed production in graminoids in the current study might be due to their capability of self-pollination. This ability allows graminoids to overcome the adverse effect of OTCs. There was a contrasting response of the other functional types to the experiment in meadow and heath vegetation. A similar variation in response of different functional types was reported for Tundra vegetation (Oberbauer et al. 2013). Forbs and evergreen shrubs showed a high fruit production in the meadow with a minimum to no increase in the heath. Contrary, deciduous shrubs had an increased fruit production in the heath with no significant increase in the meadow. Our findings were in line with those studies that reported contrasting effects of climate change on fruit production (Klady et al. 2011; Dorji et al. 2013).

Except for a weak non-significant negative effect of summer precipitation at the meadow, other precipitation regimes (i.e., summer and winter) were positively correlated with fruit production. The positive correlation was significant in heath for the previous year precipitation and total precipitation. Therefore, our hypothesis that winter and summer precipitation was negatively correlated with fruit production was rejected. The difference between heath and meadow regarding precipitation effects was likely due to the different properties of these two vegetation types. The heath is drier than meadow (Alatalo et al. 2020), and precipitation may therefore have positively affected fruit production there. Heath plants can also be more susceptible to flowering bud freezing due to the lighter snow cover on the exposed heath (Oberbauer et al. 2013). Therefore, increased previous year precipitation can increase the snow cover and delay the snow melt, thus decreasing the risk of freezing of buds and flowers, contrary an earlier onset of flowering could have a negative effect on plant reproduction of alpine plants (Iler et al. 2019).

For the heath, climatic variables of the previous year and total (previous and current) had a stronger significant correlation with total fruit production than those of the current year. Considering total fruit production, we observed that fruit production increased with precipitation and minimum temperature increase, contrary increase in maximum temperature had negative impacts on fruit production. This finding implied that the climatic variables of the previous year were more important for fruit production than those of the current year. Also, this result is in line with the fact that flowering buds in some alpine species were formed in the previous year of fruit production (Oberbauer et al. 2013; Alatalo et al. 2021).

Total fruit production in the Meadow was more affected by total and previous year temperature than Heath. An increase in maximum temperature negatively affected fruit production, but an increase in mean and minimum temperature had positive effects. Considering these results, our proposed hypothesis on the importance of minimum temperature that maximum temperature was correct. The current year maximum temperature with effects on delaying phenology and affecting pollinator actions had negative impacts on total fruit production (Alatalo et al. 2021). Both warming and timing of snow melt during the spring can affect the phenology of alpine plants, however, the effect can vary among species (Carbognani et al. 2016; Jerome et al. 2021). In addition an experimental study in Rocky Mountains showed that while plant phenology of three species (*D. nuttallianum*, *P. pulcherrima* and *Valeriana edulis*) was impacted by timing of snow-melt and warming, reproductive success was not (Jerome et al. 2021).

Forbs in both communities had a similar response to climatic variables. Current year precipitation decreased, and the previous year precipitation increased the fruit production of forbs. This finding highlighted the effects of both snow cover in winter and delayed flowering in summer on fruit productions of forbs. Except for the previous year's precipitation, the other significant climatic variables that affected forbs had stronger effects in the meadow. Depending on the vegetation type and function type (i.e., graminoids or forbs), current temperature showed variable effects on fruit production. As hypothesized, the overall correlation of the current year ambient temperature with fruit production of graminoids and forbs was positive. Fruit production of graminoids in heath and meadow showed a similar response to climatic variables. Except for the current minimum temperature that was significant in Meadow and not significant in Heath. An increase in minimum and mean temperature increased fruit production of graminoids, with an increase in maximum temperature had no adverse effects on fruit production of this functional type. This finding suggest graminoids may be favored by climate change (Wehn et al. 2014; Dolezal et al. 2019).

Except for the negative correlation of the maximum temperature of the previous year, the other climatic variables had no effects on fruit production of evergreen shrubs in heath. Contrary, fruit production of this functional type in the meadow was governed by climatic variables. The response of evergreen shrubs to climatic variables in the meadow were similar to the response of forbs in this community. Deciduous shrubs in heath showed the highest correlation to the climatic factors. Total, minimum temperature, and precipitation increase led to more fruit production in this functional type. Precipitations had a negative impact on deciduous shrubs in the meadow but a positive impact on deciduous shrubs of heath. The maximum temperature of the previous year reduced fruit production of deciduous shrubs. Flower buds of evergreen and deciduous shrubs initiate in the previous summer (Molau et al. 2005). Thus, climatic factors related to the increased risk of flowering bud freezing were negatively correlated with fruit production of shrubs, and those that decreased the risk showed a positive correlation. Therefore, our proposed hypothesis on the effects of the climatic variables on the fruit production of shrubs was partially supported. The high maximum temperature of the current year may increase the risk of early flowering and change biotic interactions. Thus, it negatively impacted the fruit-set production of shrubs (Oberbauer et al. 2013; Kudo 2021).

5. Conclusions

Our results suggest that nutrient availability is a more crucial factor limiting reproduction in high alpine plant communities. Increased atmospheric nutrient deposits due to human activities may therefore have a large impact over a longer term. Additionally, the results indicate that warmer summers due to climate change may have a limited impact on fruit production of high alpine plants. Instead, max temperatures during the fall before the fruiting year, and minimum temperatures may be more important.

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Table 1. “Type III Tests of Fixed Effects” from linear mixed models analysis, based on REML testing on the effects of year (1995, 1996, 1997, 1998, 1999, 2000, 2001) and treatment on total fruit production and on fruit production by graminoids, forbs, evergreen shrubs, and deciduous shrubs, in an alpine meadow and heath community at Latnjajaure, subarctic Sweden. Experimental treatments: warming with open-top chambers (OTC), nutrient addition, and a combined warming and nutrient addition. *Df* = degrees of freedom, *F* = F-statistics, *P* value = significance level; **bold** indicates significance at $P \leq 0.05$.

Source of variation	*df*	Total		Graminoids		Forbs		Evergreen shrubs		Deciduous shrubs	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Year	6	16.80	**0.000**	13.69	**0.000**	7.01	**0.000**	7.45	**0.000**	5.26	**0.000**
Treat	3	9.19	**0.000**	34.15	**0.000**	8.55	**0.000**	6.46	**0.000**	2.86	**0.038**
Veg	1	5.61	**0.019**	0.09	0.770	77.77	**0.000**	32.96	**0.000**	52.84	**0.000**
Y x T	18	3.51	**0.000**	4.05	**0.000**	1.58	0.066	2.56	**0.001**	1.05	0.401
Y x V	6	2.49	**0.024**	0.19	0.980	4.9	**0.000**	4.94	**0.000**	2.89	0.**010**
T x V	3	2.22	0.086	3.30	**0.021**	7.67	**0.000**	0.59	0.622	1.78	0.152
Y x T x V	18	0.80	0.694	0.78	0.718	1.37	0.147	1.14	0.311	0.77	0.738
Error	224										

Table 2. Correlation coefficients between fruit production and ambient climate parameters in an alpine heath and Meadow, at Latnjajaure northern Sweden (1995-2001). Precipitation, maximum temperature, minimum temperature and mean temperature. Pre = August, September and October before the fruit production year (i.e. the previous year). Current = May, June and July in the fruit production year (i.e. the current year). Total = the pre and current period (i.e. six months in total). **Bold** indicate statistically significance at 5% level.

Heath Climatic Parameter	Deciduous shrubs	Evergreen shrubs	Graminoids	Forbs	Total
Pre-Precipitation	**0.33**	0.06	-0.08	**0.18**	**0.21**
Current-Precipitation	0.12	0.06	0.03	-0.13	0.07
Total-Precipitation	**0.25**	0.11	0.03	-0.04	**0.18**
Pre-Max Temperature	**-0.17**	**-0.28**	-0.16	0.02	**-0.28**
Current-Max Temperature	**-0.24**	-0.11	0.03	-0.02	-0.16
Total-Max Temperature	-0.11	-0.09	0.02	-0.05	-0.10
Pre-Min Temperature	**0.25**	0.02	**0.25**	0.09	**0.28**
Current-Min Temperature	**0.37**	0.08	0.07	**0.24**	**0.31**
Total-Min Temperature	**0.49**	0.11	**0.25**	**0.28**	**0.49**
Pre-Mean Temperature	**0.17**	-0.01	**0.22**	0.06	**0.19**
Current-Mean Temperature	**0.29**	0.07	**0.18**	**0.26**	**0.33**
Total-Mean Temperature	**0.37**	0.15	**0.30**	**0.17**	**0.43**

Meadow Climatic Parameter	Deciduous shrubs	Evergreen Shrubs	Graminoids	Forbs	Total
Pre-Precipitation	0.04	**-0.14**	-0.02	**0.13**	0.00
Current-Precipitation	**-0.17**	0.06	0.10	**-0.04**	-0.03
Total-Precipitation	-0.04	0.07	0.13	**0.07**	0.08
Pre-Max Temperature	**-0.51**	**-0.20**	-0.20	-0.15	**-0.43**
Current-Max Temperature	-0.03	**0.17**	0.00	0.00	0.04
Total-Max Temperature	**-0.20**	0.14	0.03	-0.02	-0.03
Pre-Min Temperature	0.15	**0.35**	**0.31**	**0.44**	**0.46**
Current-Min Temperature	**-0.17**	**0.19**	**0.19**	0.15	0.12
Total-Min Temperature	**0.19**	**0.38**	**0.37**	**0.53**	**0.54**
Pre-Mean Temperature	-0.09	**0.37**	**0.29**	**0.27**	**0.30**
Current-Mean Temperature	0.03	**0.37**	**0.28**	**0.29**	**0.35**
Total-Mean Temperature	**0.20**	**0.54**	**0.42**	**0.43**	**0.59**

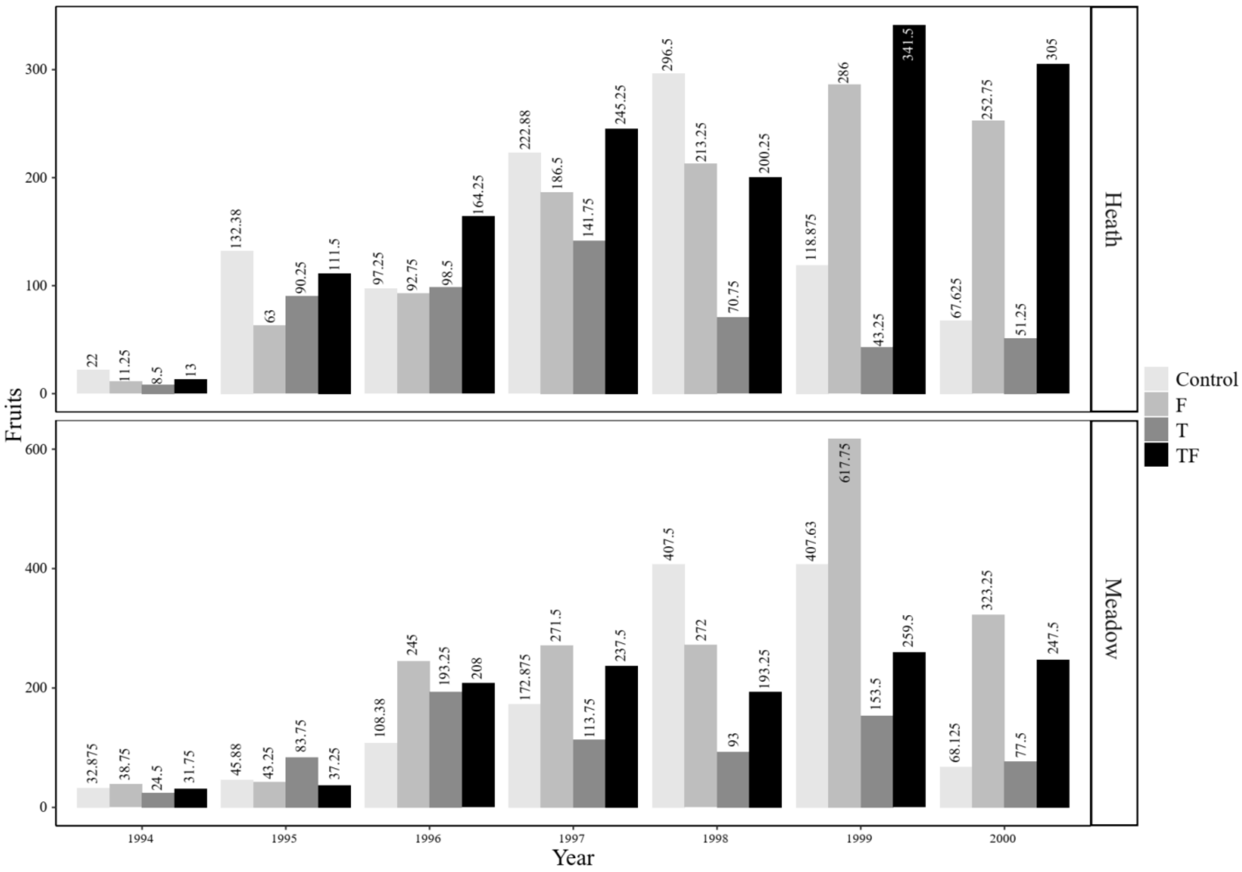
Significance of r (minimum value for 0.165 for 5% for 140 sample)

Figure legends

Fig. 1. Response in terms of total fruit production (fruit production by all species) across treatments in 1994 -2000, in an alpine heath (top) and meadow community (bottom) at Latnjajaure, subarctic Sweden. Treatments: control (C), warming with open-top chambers (T=temperature), nutrient addition (F=fertilizer), and combined warming and nutrient addition (TF). N = 8 plots for control, 4 plots for T, F and TF.

Fig. 2. Response in terms of fruit production of deciduous and evergreen shrubs, forbs and graminoids across treatments in 1994 -2000, in an alpine heath and meadow community at Latnjajaure, subarctic Sweden. Treatments: control (C), warming with open-top chambers (T=temperature), nutrient addition (F=fertilizer), and combined warming and nutrient addition (TF). N = 8 plots for control, 4 plots for T, F and TF.

Fig. 1.


Fruits
Year
Heath
Meadow
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1995
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63
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97.25
92.75
98.5
164.25
222.88
186.5
141.75
245.25
296.5
213.25
70.75
200.25
118.875
286
43.25
341.5
67.625
252.75
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305
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43.25
83.75
37.25
108.38
245
193.25
208
172.875
271.5
113.75
237.5
407.5
272
93
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407.63
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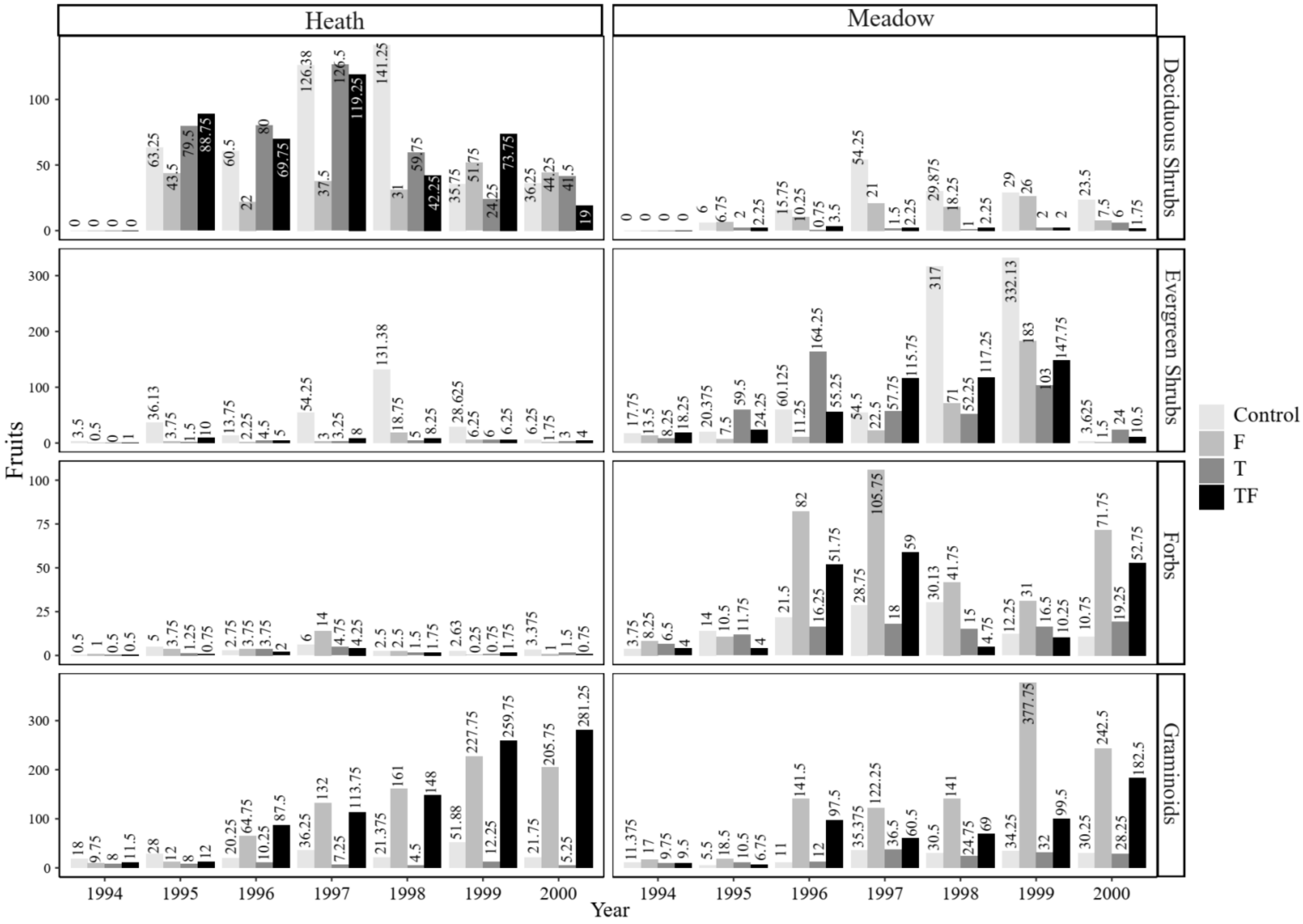
Fig. 2.


Heath
Meadow
Deciduous Shrubs
Evergreen Shrubs
Forbs
Graminoids
Fruits
Year
1994
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0 0 0 0 6 6.75 2 2.25 15.75 10.25 0.75 3.5 54.25 21 1.5 2.25 29.875 18.25 1 2.25 29 26 2 2 23.5 7.5 6 1.75
3.5 0.5 0 1 36.13 3.75 1.5 10 13.75 2.25 4.5 5 54.25 3 3.25 8 131.38 18.75 5 8.25 28.625 6.25 6 6.25 6.25 1.75 3 4
17.75 13.5 8.25 18.25 20.375 7.5 59.5 24.25 60.125 11.25 164.25 55.25 54.5 22.5 57.75 115.75 317 71 52.25 117.25 332.13 183 103 147.75 3.625 1.5 24 10.5
0.5 1 0.5 0.5 5 3.75 1.25 0.75 2.75 3.75 3.75 2 6 14 4.75 4.25 2.5 2.5 1.5 1.75 2.63 0.25 0.75 1.75 3.375 1 1.5 0.75
3.75 8.25 6.5 4 14 10.5 11.75 4 21.5 82 16.25 51.75 28.75 105.75 18 59 30.13 41.75 15 4.75 12.25 31 16.5 10.25 10.75 71.75 19.25 52.75
18 9.75 8 11.5 28 12 8 12 20.25 64.75 10.25 87.5 36.25 132 7.25 113.75 21.375 161 4.5 148 51.88 227.75 12.25 259.75 21.75 205.75 5.25 281.25
11.375 17 9.75 9.5 5.5 18.5 10.5 6.75 11 141.5 12 97.5 35.375 122.25 36.5 60.5 30.5 141 24.75 69 34.25 377.75 32 99.5 30.25 242.5 28.25 182.5
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