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Differences in the time of flowering in populations of European Golden Rod (*Solidago virgaurea*) on the Åland Islands, SW Finland

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In northern Åland, SW Finland, I discovered that the yearly development of the Golden Rod (*Solidago virgaurea*) most probably is dependent on light and partly on the effective temperature sum. The plants, growing on bare cliffs in northern Åland, start flowering about 1,5 months earlier than the plants of the interior of Åland but are much shorter. This may probably be an effect of phenotypic plasticity but may also depend on genetic factors. Plants from the cliffs will, when transplanted to the interior, flower at about the same time as on the cliffs if given enough light. If not, they will flower later and, in any way, they are very small, just like their origins. This speaks in favour of light being a key factor in the development and that the plants of the interior are poor competitors.

Introduction

The plant genus *Solidago* is predominantly found in the northern hemisphere, where most of the species flower in late summer or in the autumn. There are about 190 species of *Solidago* (Fursenco et al. 2020). Most of them, about 125, are found in North America (Niering and Olmstead, 1979), while here in Europe, we have just one domestic species, the European Golden Rod (*Solidago virgaurea* L.) and a few introduced species (Weber 2001). For several years now, I have noticed that the common Golden Rod starts flowering much earlier in the archipelago and on the coastal margins of the Åland Islands, than in the interior parts of the landscape. In 2022, I (RC) decided to take a closer look at the flowering and noticed that the flowers of the archipelago were fully in blossom on the first of June, while I had to wait until July 15–20, before I saw the first flowering plant in the interior.

I then decided on how to ensure that my experiments would give a clue to what were the reasons for differences in flowering time

Research area

The Åland Islands are located at about 60° N, 20° E (Fig. 1). More than 6 500 islands and skerries cover an area of about 13 325 km^2 and the main island has an area of about 1 000 km^2. The bedrock of the main island consists mainly of different acidic rapakivi granites, while the bedrock of the archipelago between the main island and Finland is composed of older bedrock, consisting of gneisses, migmatites and related kinds of rocks (Bergman 1986). The bedrock at low or medium altitudes is covered by lodgement till, which is rich in calcium due to limestone deposits on the bottom of the Bothnian Sea. Above the lodgement till, we usually find clay, now transformed

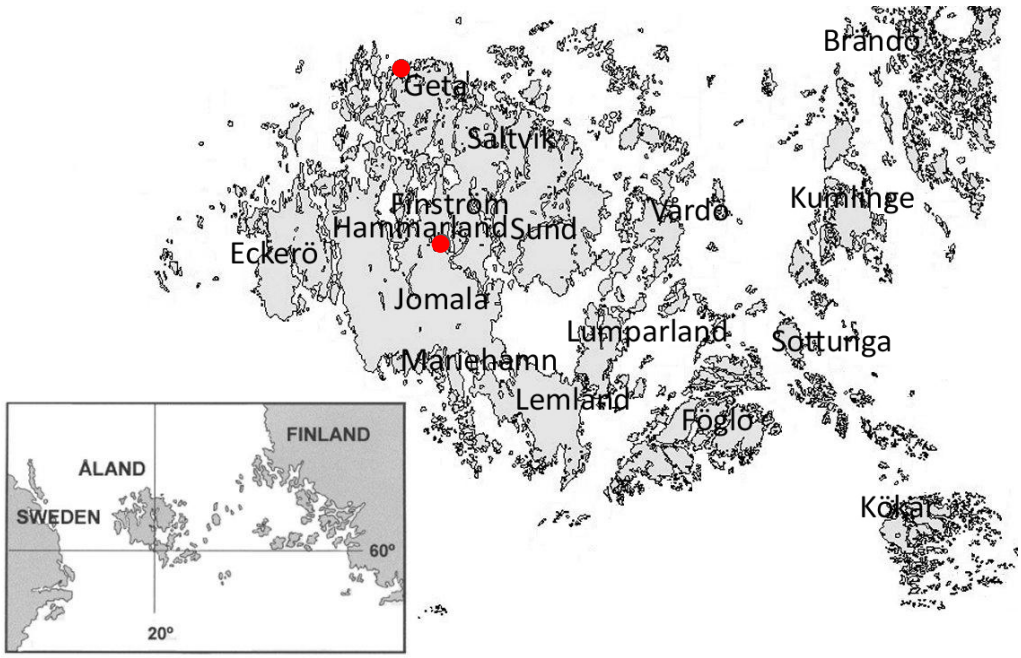

Fig. 1. The Åland Islands are located between Sweden and Finland. The sites of the study are marked with red dots.

to arable land. At higher altitude we mainly find pine forest on rocky ground, but in between we also find spruce forests or even deciduous forests.

The main island is rather dissected and full of fissures and cracks due to faults in ancient times. The main island is generally covered by forest in areas where it is not built up or covered by fields for agriculture or grazing grounds. The margins of the main island consist of bare rocks with very thin soils.

The climate is rather mild with a yearly mean temperature of 6.7 °C and an annual precipitation of 586 mm (Fig. 2) (Finnish Meteorological Institute).

Material and methods

I decided to follow the populations of golden rod at two locations. The first one is Havsöra, a promontory in the municipality of Geta, on the northern margin of the main island. The promontory is about 2 km long, stretching from SSE to NNW. The innermost part of the promontory is dominated by pine forest on rocky ground while the outer parts are dominated by bare rocks, a few boulder fields and a grove of pine trees. All the experiments have taken place on the outermost km of the promontory in the years 2023 and 2024, starting with the transplantation of plants in the fall of 2022.

The second set of experiments was performed in the municipality of Finström, in the middle of the Åland Islands. This location is as far from the open sea as one could wish, but with some lakes in the vicinity. The locality is along the forest along an unpaved road and forests, pastures and a few fields dominate the landscape. The first locality (2022–2023) was across the road ditch along the forest with an easterly aspect. Next year I moved the place of transplants to a clear-cutting some hundred metres further north. I also measured the height of 100 naturally flowering plants at both locations.

The investigation consisted of two parts – seed growing experiments and reciprocal as well as internal transplants of plants. In October 2022, seeds from golden rods were collected from Havsöra and Finström and planted in 7 pots in my garden in Mariehamn and to 600 pots in Uppsala, where a biologist friend planted and grew them. The pots where the seeds were planted were put

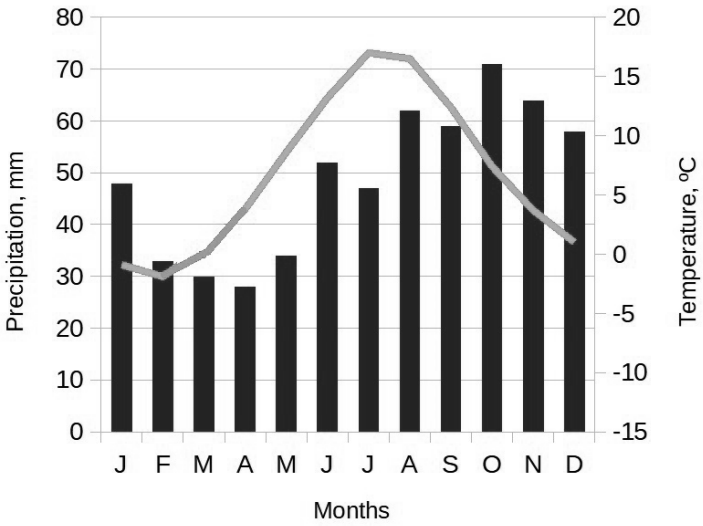

Fig. 2. Climate graph for Mariehamn for the normal period 1991–2020. Data from Finnish Meteorological Institute.

outdoors to ensure that the seeds would be properly objected to vernalisation. At about the same time I transplanted 7 plants from Finström to Havsöra and vice versa. The transplantation experiments were repeated the following year.

Results

In one of the most used floras (Mossberg et al. 1992) it is concluded that the Golden Rod will flower in July–September. This is true for the inland observations of the Åland islands too, but when it comes to the margin or the insular areas, flowering starts much earlier, as early as in the last week of May/early June.

The first signs of flowering on Havsöra were seen on May 24 when big flower buds occurred and one week later (June 3) the flowers had burst. June is the main month for flowering, while July is a time of wilting and maturing of seeds. During the latter half of August some of the plants were having a second period of flowering and some flowers were seen on August 29. On the interior location, flowering started at about July 15, with the strongest flowering during August and some scattered occurrences in September and the last flowers were seen on October 6. No second set of flowers could be observed on the interior location.

Regarding the plantation of seeds, the experiments failed on the Åland islands as well as in Uppsala, since we had no germinating seeds at all.

The average heights of the natural plants were 77.5 ± 14.4 cm in the interior and 22 ± 7 cm on the cliffs.

I had more luck with the transplantation experiments, even though the experiments succeeded better in one direction than the other. Five of the seven transplants from central Finström to Havsöra started to flower in the first weeks of June and the remaining two had perished.

In Finström, all the internal transplants were alive with just a few leaves, just like the plants of the surroundings. Of the plants transferred from Havsöra, it seemed like they were all alive, but not yet ready for continued growth at the end of May. Thus, all of the transplants were still alive and waiting for some signal of growth. In the middle of July, I visited Finström and then I found that three of seven plants from Havsöra were just about one week from flowering, thus at the same time level as the surrounding population of golden rods while the other plants could not be found. The results of the internal transplants were negative, i.e. all the plants had died but, in the surroundings, goldenrods were flowering. On the second of August, two of the plants transplanted from Havsöra were flowering, but were very short compared with the surrounding plants.

The winter 2022–2023 was rather mild, and we had to wait for snow for until March, so by the beginning of spring, we finally had some

snow. This made it difficult to explain differences in the plantations but could also be explained by the fact that the plants require a certain temperature to start developing. Another factor was that the spring and the beginning of summer were extremely dry, and this drought actually lasted until July. In June we had only 3 mm of rain.

Next year, after having introduced new transplants in August, the new transplants (9 of 11) were about to start flowering in the first week of June, at about the same time as the plants from where they originated and in the last week of June, they were fully in blossom. On July 20, I measured the plants, which were 21.8 ± 7 cm high, thus the same height as the plants from which they originated. At Havsöra (also the first week of June) I had some troubles, some of the plants had died and other had been covered by sand (wave activity) or otherwise disappeared. Of about 25 plants, I managed to find 13, which were starting to flower and just one plant with leaves but no blossoms.

Discussion

The mild winter of 2022–2023 and the lack of snow explain some of the results but could also be explained by the fact that the plants require a certain temperature sum to start developing, the so called effective temperature sum (ETS).

ETS, the sum of the positive differences between diurnal mean temperatures and 5 °C, is used in ecology, agriculture, forestry, and hydrology. ETS determines the distribution of plants in e.g. countries or continents but also the onset of e.g. growth, flowering and seed germination, thus defining the so called growing season and the growing zones.

One explanation is that the plants on the rocks, that start flowering around late May early June, reach the critical ETS for flowering earlier, being heated by the sun, while the soils where other populations of golden rods grow, are heated more slowly. A more likely explanation is the removal of the transplants to a clear-cutting leading to more light. The place of the first transplants from Havsöra to Finström was a forest edge where the direct sun light was eliminated in the middle of the day, leaving the transplants in shade.

During the period of investigation, the weather has varied from year to year, with a cooler April and a much warmer and dryer May (only 3 mm of rain) in 2024.

In Japan, a group of researchers (Sakaguchi et al. 2019) reached similar results when transplanting plants from the bedrock of serpentine. The similarity is perhaps not comparable as the rapakivi granite is acidic, while the serpentine is mafic. The two types of bedrock, have one thing in common; they are both poor in plant nutrients. Another investigation was carried out at Mt. Norikura, also in Japan (Sakurai & Takahashi 2017) and they reached the conclusion that the plants started to flower at higher elevations, where the environmental conditions are harsher, earlier than at lower elevation. This may also be true for the population at bare bedrock, close to the sea, where winds are steadily blowing and no tree shade the plants, which thus are subjected to direct sunlight.

Conclusions

I believe that there are two types of golden rod; one that starts to flower very early (end of May-early June), and another, beginning to flower gently after mid-July, and then begins to flower more properly from the beginning of August till mid-August. After that, the flowering continues into late October, when the risk of night frost increases.

The variety, that starts flowering in May and continues to flower for a long time, with a peak in late June, but at the end of July, we will find almost exclusively dwarf-grown specimens, confined to crevaces in the bedrock (Fig. 3). The common variety, that starts flowering in mid-July early August, shows a diffuse beginning but suddenly it appears and will do so until the middle of September.

The differences in behaviour are most likely due to direct or indirect heating by the sun and even more by the effect of direct sunlight. The plants, growing on the cliffs by the sea, are more likely to receive both direct sunlight and more heat from the sun, as the cliffs are heated much faster than the soils, where the inland plants are growing. Thus, they reach a threshold value for further development earlier than the interi-

Fig. 3. Golden Rods on Havsöra in the end of June. Note the harsh environment, with plants growing in crevices or on patches of soil.

or plants. In the interior positions, light is much scarcer than on the cliffs. In those positions (natural place for the species) they are poor competitors, shaded by other trees and have no possibilities to flower earlier than in the middle of summer.

In some respects, the differences depend on the environment, but the small size of the plants from Havsöra is indicative that there also may be some kind of genetic differentiation. More research should be carried out to find the reasons for this phenomenon and to investigate whether this is a very local phenomenon or if it also exists in other archipelago areas along the coasts of the Baltic Sea.

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