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Phenology of *Heracleum mantegazzianum* Sommier & Levier (Apiaceae) Plants in the Middle Taiga Subzone of the Komi Republic

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Abstract—Long-term observations of seasonal development of *H. mantegazzianum* in the Middle Taiga subzone of the Komi Republic revealed that phenorhythm types belonging to different phenotypic classes were present in the species populations. Juvenile plants developed according to the spring–autumn-green phenorhythm type with the periods of summer and winter dormancy. Immature and virginal plants were characterized by the spring–summer–autumn-green phenological type with the period of winter dormancy. Generative plants showed the spring–summer-green phenorhythm type, with the shortest vegetation season compared to other phenotypic classes. The general spring–summer–autumn-green phenological seasonal development type with the winter dormancy period typical for the self-sustaining populations of *H. mantegazzianum* ensured the species dominance over other herbaceous plants during the vegetation season. Dispersal of *H. mantegazzianum* seeds in different parts of the invasive range started when environmental heat amounts were at a relatively constant level. The sum of active air temperatures ≥ 5°C (SAT5) averaging 1662 ± 176°C and 113 ± 12 SAT5 days can be recommended as a predictor of the start of invasive hogweed mericarpia dispersal period. In urban locations, phenological phases of *H. mantegazzianum* came 1–2 weeks earlier than in the suburbs, which should be taken into account when implementing plant eradication measures.

Keywords: phenology, phenorhythm type, phenotypic class, *Heracleum mantegazzianum*, invasion, sum of active temperatures

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INTRODUCTION

Phenological observations make records of periodic events in the plant life cycle, which allows identifying specific features of plant seasonal development, assess the impact of environmental factors on the growth and adaptive potential of plants in nature or under cultivation conditions (Zhmylev et al., 2003). Plants that are similar in duration, time of the start and the end of vegetation period, and the directions of changes in the key phenological states (vegetation and dormancy) are combined into phenological types (phenorhythm types) (Borisova, 1972).

One of the directions in phenological observations program includes the study of seasonal development cycles of alien (invasive) species (Minin et al., 2020; Methodology of management..., 2023), which may cause significant environmental, economic, and social damage (Boardman et al., 2022). The results of phenological observations are used to test the theoretical foundations of invasion biology (Wolkovich and Cleland, 2011; Park et al., 2024) and to develop approaches for alien plant management (Singh et al., 2018; Taylor et al., 2020).

In Russia, technologies for alien species elimination are included in the list of the most important science-driven technologies (Decree of the President of the Russian Federation no. 529 signed June 18, 2024). In 2025, amendments were adopted to the Land Code of the Russian Federation and the legislative acts related to land protection from alien plants (Federal Law no. 294-FZ signed July 31, 2025).

Currently, *Heracleum sosnowskyi* Manden. and *H. mantegazzianum* Sommier & Levier, which belong to the complex of invasive giant (tall) hogweeds, are widely distributed among the invasive flora of Europe. These species are characterized by high ecological similarity (Ecology and management..., 2007; Zakhozhii et al., 2022; Dalke and Chadin, 2023) and phylogenetic relatedness (Shadrin et al., 2024). This gives us a reason to refer to the populations of the invasive giant hogweed under study as *H. mantegazzianum* (giant hogweed), recognizing that *H. sosnowskyi* (Sosnovsky's hogweed) is conspecific with *H. mantegazzianum* at least within the studied part of the secondary range (Dalke et al., 2024b).

When invading new territories, coenopopulations *of H. mantegazzianum* form communities with low species abundance, where phenotypic classes of plants can be distinguished (Krylov et al., 2020) occupying different niches within the community and ensuring the stability of coenopopulations under unfavorable environmental conditions. Based on the size and functional characteristics *of H. mantegazzianum* plants, the following main phenotypic classes can be defined: (1) seedlings and juvenile plants, (2) immature and virginal plants, and (3) generative plants. Their presence in the population allows taking advantage of the entire space capacity, effectively use environmental resources, and regulate phytocenosis microclimate (Tappeiner and Cernusca, 1998; Dalke et al., 2024a, 2024b).

In the course of phenological studies of alien species, it is recommended to focus on the phenophases when plants can cause most harm to human health and ecosystems—for example, mass flowering *of Ambrosia artemisiifolia* L. or flowering, fruiting, seed dissemination of *Heracleum sosnowskyi* Manden., *Hordeum jubatum* L., and *Solidago canadensis* L. (Methodology of management..., 2023). Given the large scale of giant hogweed invasion (Ecology and management..., 2007; Ozerova and Krivosheina, 2018; Zakhozhii et al., 2022), it is important to study the patterns of seasonal changes in plants in the regions of invasion. Attention should be focused on the dispersal period of *H. mantegazzianum* diaspores, which is closely related to invasion dynamics (Krivosheina et al., 2020; Chadin et al., 2021; Dalke and Chadin, 2023) and development of plant number control measures (Dalke et al., 2025).

The aim of the present work was to study phenological development of *H. mantegazzianum* plants in the Middle Taiga subzone of the Komi Republic, taking into account the stages of studied plants. Based on our own observations and literature data, we evaluated the climatic conditions during the dispersal period of *H. mantegazzianum* mericarpia in different parts of its invasion range.

MATERIALS AND METHODS

Phytophenological observations of *H. mantegazzianum* plants were carried out at the permanent sites located on the territory of Urban District Municipal Formation Syktyvkar (Middle Taiga subzone of the Komi Republic) in the period 2020–2025. Plants grew in abandoned agricultural areas in the suburbs (plot coordinates: 61.645609° N, 50.731871° E; 61.607507° N, 50.735460° E; 61.702009° N, 50.818681° E) and near urban communications and buildings (plot coordinates: 61.648147° N, 50.837840° E; 61.662855° N, 50.822206° E; 61.651473° N, 50.816500° E).

The study area is characterized by moderate continental climate, with cold summers. The average daily temperature of the warmest month (July) is 17°C, of the coldest (January) is –16°C. Annual precipitation amount is about 700 mm. Snow cover is established in the first decade of November, snow melts in late April–early May. The average daily air temperature passes the 0°C threshold in the second decade of April and in early October. The duration of frost-free period reaches 190 days (*Atlas Respubliki Komi*..., 1997).

Stages of *H. mantegazzianum* were identified by the shape and dissection type of leaf blades (Kudinov et al., 1980; Satsyperova, 1984). Plants growing in open well-illuminated areas were studied. In the course of regular inspections of cenopopulations, the start and end dates of the following periods (phenophases) were recorded:

— vegetation period and summer and winter dormancy for seedlings and juvenile plants;

— vegetation period and transition to winter dormancy for immature and virginal plants;

— vegetation period, bud formation, flowering, fruiting period, aboveground parts dying-off, and seed dispersal for generative plants.

In this species, it is not possible to distinguish a postgenerative (senile) period as proposed by A.A. Uranov (Uranov, 1975). Classifying the ways of plant population development, Uranov and Smirnova considered that populations of monocarpic species "... do not have a senile period in their life cycle" (Uranov and Smirnova, 1969). Our long-term observations and assessment of physiological condition of monocarpic *H. mantegazzianum* plants show that in the conditions of the Middle Taiga subzone, aboveground and underground organs of generative plants die off at the start of the seed dispersal period, which indicates the completion of the large life cycle and the absence of the senile period.

The term "seeds" is used conditionally hereafter. The fruit of Apiacea representatives is a cremocarp. In hogweed, the fruit separates into two mericarps at maturity, with each containing a single seed (Satsyperova, 1984). Since it is extremely difficult to determine the moment when juvenile plants transit into the state of summer dormancy without damaging the plant stand, the date of bud formation completion in generative plants, when the leaf index reaches its highest values in the coenopopulation, was used as its proxy (Dalke et al., 2024b).

The results of observations were recorded in diaries (http://proborshevik.ru/phenology). Phenorhythm types were determined based on the duration of the vegetation period, and the presence and type of plant dormancy periods (Borisova, 1972).

To estimate the times of seed maturation and dispersal, literature data on hogweed biology under introduction (Marchenko, 1953; Koyushev, 1969; Alexandrova, 1971; Kudinov et al., 1980; Skupchenko, 1989) and invasion (Otte and Franke, 1998;

Panasenko and Kholenko, 2017; Dalke et al., 2019, 2024a) conditions were analyzed.

Environmental conditions in *H. mantegazzianum* growing areas were described using the climatic parameters calculated on the basis of meteorological observations obtained from specialized datasets: Weather Schedule (https://rp5.ru), VNIIGMI-MTsD (http://aisori-m.meteo.ru), and GHCN-Daily (Menne et al., 2012). Given high cold resistance of invasive hogweed (Dalke et al., 2019; Zakhozhii et al., 2022), heat accumulation in the environment was estimated by the sum of daily average air temperatures ≥ 5°C (SAT5, °C) and the duration of the SAT5 period (number of SAT5-days). Water availability in the areas was determined by the amount of atmospheric precipitation (mm) and the Selyaninov hydrothermal coefficient (HTC), calculated as the ratio of the amount of atmospheric precipitation (precipitation × 10) to the sum of daily average air temperatures ≥ 10°C (SAT10). The possibility of hogweed seeds shedding and dissemination by anemochory was estimated based on gust velocity (m/s) (Chadin et al., 2021).

For statistical description of the collected data, the mean value and standard deviation were used. Calculations and plotting were performed in the R environment (https://www.R-project.org).

RESULTS

Observations of plant growth and development in the Middle Taiga subzone of the Komi Republic have shown that *H. mantegazzianum* populations are characterized by regular annual fruiting. Most seeds are disseminated during the period from August to October, while diaspores remaining in the inflorescences continue shedding during the autumn–winter period (Fig. 1). The snow cover formed in October–November remains till the late April of the following year.

Seedling and Juvenile Plant Phenology. Seed germination begins and true leaves appear after the melting of snow cover (late April–early May, SAT5 = 26 ± 21°C over 107 ± 6 days from the start of the year) (see Figs. 1a and 1b). Intensively developing seedlings transit to the juvenile stage within two to three weeks. In well-illuminated areas, seedlings and juvenile plants often form uniform clusters. After the leaves of immature, virginal, and generative age plants have formed a dense canopy, juvenile plants start their transit to the summer (secondary) dormancy phase and loose leaves. The transition to secondary dormancy in juvenile plants was observed in mid-July (SAT5 = 1156 ± 196°C over 180 ± 5 days from the start of the year). After the leaves of generative plants die off (second half of August, SAT5 = 1731 ± 136°C over 234 ± 8 days from the start of the year), juvenile plants come out of their summer dormancy and continue growing untill the daily average temperatures have decreased to 0°C (second half of October, SAT = 2226 ± 69°C over 295 ± 8 days from the start of the year). After the death of their aboveground parts, *H. mantegazzianum* plants enter the winter dormancy phase (see Fig. 1a).

Immature and Virginal Plant Phenology. Immature and virginal plants started growing 17 ± 4 days after the emergence of hogweed seedlings (early May, SAT5 = 71 ± 29°C over 124 ± 5 days from the start of the year). After a short rosette stage, hogweed leaves grow intensively reaching 1.5 m in height. Immature and virginal *H. mantegazzianum* plants retain their aboveground organs and vegetate till the formation of the snow cover (see Fig. 1a). Plants in these stages also transit to winter dormancy after the dying-off of their aboveground parts (second half of October, SAT5 = 2226 ± 69°C over 295 ± 8 days from the start of the year).

Generative Plant Phenology. Growth of generative individuals begins simultaneously with the growth of immature and virginal plants (early May, SAT5 = 71 ± 29°C over 124 ± 5 days from the start of the year) (see Figs. 1a and 1b). Flower buds appear on *H. mantegazzianum* plants in early June. The buds are brought above the leaf canopy as a result of intensive stem growth, and the plants begin to flower (late June–early July, SAT5 = 772 ± 96°C over 180 ± 5 days from the start of the year). Flowering usually lasts for up to two weeks (first half of July, SAT5 = 1068 ± 103°C over 195 ± 6 days from the start of the year). Fruiting phase (fruit maturation) begins in the second half of July and lasts till mid-August (SAT5 = 1580 ± 96°C over 225 ± 4 days from the start of the year). Dispersal of *H. mantegazzianum* seeds together with leaf death and drying of the generative shoot begins in mid-August. Most seeds are shed before October. A small number of diaspores remain in the inflorescences and gradually fall down onto the ground or snow cover during the autumn–winter period.

According to our observations, the growing season of pregenerative *H. mantegazzianum* plants lasts 179 ± 10 days on average. The growing season of generative plants ended with the of plant death and the start of seed dispersal and was almost twice as short—101 ± 7 days.

Analysis of meteorological conditions in different regions of the *H. mantegazzianum* secondary range showed that hogweed seed dispersal phase started 113 ± 12 days (minimum 93 and maximum 138 days) after the start of SAT5 counting (Fig. 2). By this time, the heat amount in the environment, based on SAT5, was 1662 ± 176°C on average (minimum 1341 and maximum 2074°C). The coefficient of variation of SAT5 and SAT5-days did not exceed 11%.

Analysis of precipitation and heat accumulation data showed that plants had enough available moisture in the Syktyvkar area. During the invasive hogweed vegetation period, the sum of precipitation averaged 336 ± 85 mm, and the hydrothermal coefficient averaged 1.4 ± 0.5 over this period, which is typical for areas with excessive moisture (see Figs. 1c and 1d).

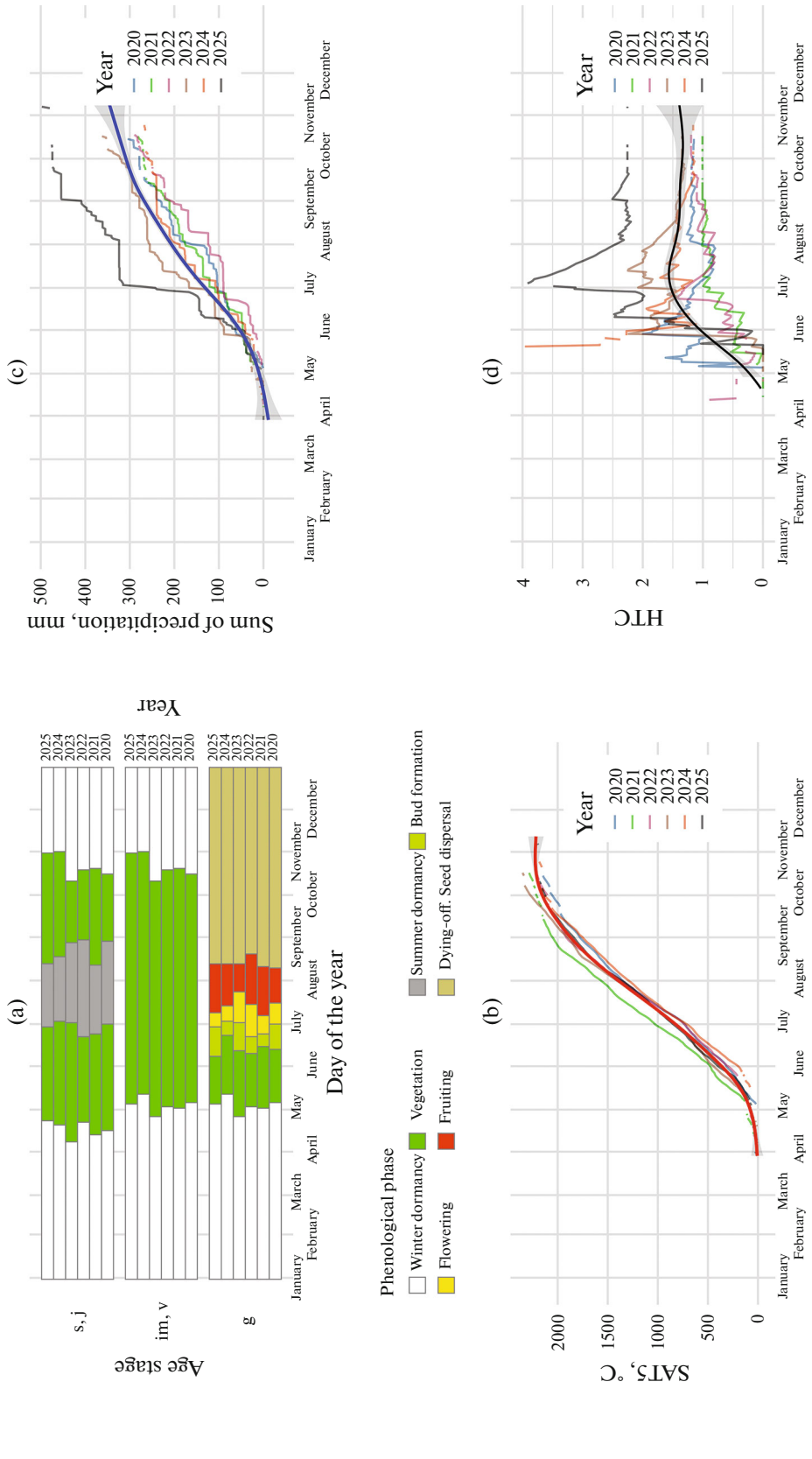

Fig. 1. Phenospectra of *Heracleum mantegazzianum* plants and weather and climatic conditions in the Syktyvkar area in the period from 2020 to 2025: (a) Phenological spectra of plants at different age stages: s, j—seeds and juvenile plants, im, v—immature and virginal plants, and g—generative plants; (b) accumulation of the sum of active temperatures ≥ 5°C (SAT5); (c) sum of precipitation, and (d) Selyaninov hydrothermal coefficient (HTC).

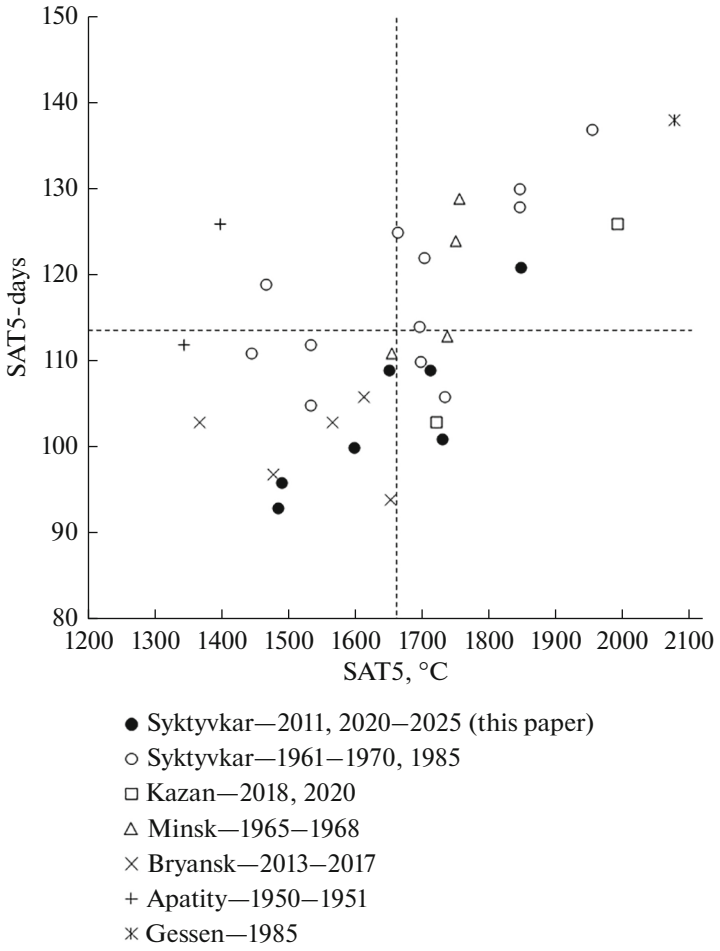

Fig. 2. Heat amount in the environment at the start of *Heracleum mantegazzianum* seed dispersal period in different years of observation*: SAT5—sum of active temperatures ≥5°C; SAT5-days—number of days from the start of SAT5 counting; dashed lines indicate the sample average (n = 34). * Note: Data on the phenological phase start times that are not the authors' own observations were obtained from the literature (Marchenko, 1953; Koyushev, 1969; Alexandrova, 1971; Kudinov et al., 1980; Skupchenko, 1989; Otte and Franke, 1998; Panasenko and Kholenko, 2017).

According to our observations, the phenological phases of *H. mantegazzianum* plants growing near residential buildings, industrial buildings, and communications in Syktyvkar occurred, on average, by 11 ± 3 days earlier than in the case of plants growing in the suburbs.

DISCUSSION

Specific phenological features of invasive species may contribute to their successful reproduction and occupation of new territories within the secondary range by facilitating the use of free phenological niches as a "window of opportunity" in their competition with local species (Gioria et al., 2026). *H. mantegazzianum* is capable of forming communities with low species abundance both in the native (Tappeiner and Cernusca, 1998; *Ecology and management...*, 2007) and the invasive parts of their range (Otte and Franke, 1998; Panasenko and Kholenko, 2017; Dalke et al., 2024a, 2024b). Formation of communities with low species abundance predominated by *H. mantegazzianum* became possible as a result of the simultaneous existence of three phenotypic classes in *H. mantegazzianum* populations, which can be grouped by the stage: (1) seedlings and juvenile plants; (2) immature and virginal plants, and (3) generative plants.

The results of our observations have shown that in the Middle Taiga subzone of the Komi Republic, *H. mantegazzianum* plants belonging to different phenotypic classes differ in the alternation patterns of vegetation and dormancy periods and the start time and length of phenological phases:

(1) juvenile plants do not grow during the entire vegetation season—first, they develop according to the spring-green phenorhythm type (Borisova, 1972), then transit to summer dormancy, and after leaving

dormancy, continue to vegetate as autumn-green plants;

(2) immature and virginal plants grow during the entire vegetation season from spring to the formation of snow cover, which means that they are characterized by a spring–summer–autumn-green phenorhythm type;

(3) generative plants grow during a part of the vegetation season from spring to early autumn showing a spring–summer-green phenorhythm type.

Considering the dynamics of seasonal development and abundance of *H. mantegazzianum* in all phenotypic classes, the populations of this species in the Middle Taiga subzone can be characterized as long-vegetating with the spring–summer–autumn-green phenorhythm types with winter dormancy.

The presence of rhythmological groups—plants with different phenorhythm types within a population fits well into the concept of the "biological hedging" strategy of *H. mantegazzianum*, which is aimed at distributing plants into phenotypic classes—groups that differ in their ability to use different resource niches (Krylov et al., 2020; Dalke et al., 2024a).

In tall-grass thickets, *H. mantegazzianum* plants mostly compete for light (Tappeiner and Cernusca, 1998; Dalke et al., 2024b). Growth of the aboveground parts of hogweeds belonging to different phenotypic classes causes mutual shading during the vegetation season. Generative plants significantly outperform other plants in height and leaf surface area. In summer, the leaves of generative plants are located in the upper part of the canopy and considerably shade the other plants absorbing most of the coming light energy. In this situation, juvenile plants use the "time windows" of the spring and autumn periods for growth, when they are not shaded by the leaves of other plants. The growth of generative *H. mantegazzianum* plants begins 2–3 weeks later than the growth of seedlings in spring, and in the second half of August, generative plants begin to die thus opening the access to light for the plants of other phenotypic classes in autumn.

The ability of juvenile plants to enter summer (secondary) dormancy is not just an adaptive feature which allows them to overcome the period with very low light availability close to the soil surface, it also ensures rapid recovery of the population in the case when plants of other phenotypic classes are destroyed (Dalke et al., 2024a).

To date, a considerable amount of data on the developmental rhythms of generative *H. mantegazzianum* plants in different parts of the species secondary range has been reported (Marchenko, 1953; Koyushev, 1969; Alexandrova, 1971; Kudinov et al., 1980; Skupchenko, 1989; Otte and Franke, 1998; Panasenko and Kholenko, 2017; Dalke et al., 2024a, 2024b). This allowed us to define the conditions required for the key phenological phase of this invasive species, seed dispersal, to start. Calendar dates are of little use for predicting the start of phenological phases because of the large size of the invasive *H. mantegazzianum* range and variability of ecological and climatic conditions that determine the start of vegetation season. For example, in the south of the invasion range (Bryansk, Minsk), hogweed seeds shed in July (Kudinov et al., 1980; Panasenko and Kholenko, 2017), and in the north (Apatity and Syktyvkar), it happens much later—in August–September (Marchenko, 1953; Koyushev, 1969; Dalke et al., 2024a, 2024b).

At the same time, according to the results obtained in different years and in different parts of the giant hogweed secondary range, heat amount in the environment at the start of seed dispersal period averaged 1662 ± 176°C SAT5. This amount of heat was accumulated over 113 ± 12 SAT5 days. The low variability of the obtained values allows considering SAT5 and SAT5-days values as predictors of the start of *H. mantegazzianum* diaspore dispersal period under the ecological and climatic conditions corresponding to the generalized data.

Year-to-year variation in the start times of phenological phases is most often associated with changes in weather conditions and hybridization between the representatives of the *Heracleum* genus in the course of introduction (Kudinov et al., 1980; Satsyperova, 1984). In addition to these reasons, the early start of *H. mantegazzianum* phenological phases in urban areas compared to the suburbs may be due to the "urban heat island" effect, which leads to air temperatures differing between the city center and the surrounding areas by 0.5–3 to 10°C (Heisler and Brazel, 2010; Ji et al., 2021). The phenomenon of phenological phases start time shift characteristic of urban vegetation (Dvoinova and Dudnik, 2025) should be taken into account when implementing measures for invasive species elimination (Dalke et al., 2025).

It is believed that the model of seasonal development is fixed in the genome, is an adaptive feature of a species, and reflects the history of its formation in certain soil-climatic and phytocenotic conditions (Zhmylev et al., 2003). We have not found any data on the phenorhythm types of *H. mantegazzianum* in its native range in the available literature. However, the study of the phenorhythmological composition of phytocenoses on the northern macroslope of the Caucasus Nature Reserve shows that the spring–summer–autumn-green phenorhythm type is the most widespread, with species characterized by this phenorhythm type being found from the foothill to Alpine phytocenoses. The spring growth of most species starts in April–May after the snow cover has completely melted, while the death of aboveground parts or leaf fall is observed in September–October (Spasovskii, 2014).

According to our data, the natural habitats of *H. mantegazzianum* in the Caucasus are highly similar

in their climatic conditions to the taiga zone of the European Northeast (Dalke et al., 2026). Thus, *H.mantegazzianum* plants growing in geographically remote areas are characterized not only by similar structural and functional parameters and productivity, but also, apparently, by a similar type of seasonal development.

In the polydominant subalpine tall-grass communities of the Caucasus, the representatives of the *Heracleum* genus have to compete with other tall-grass species including *Angelica tatianae* Bordz., *Milium effusum* L., *Cephalaria gigantea* (Ledeb.) Bobrov, and *Rumex alpinus* L. (Dudova et al., 2019; Gulov et al., 2022). The subdivision of the *H. mantegazzianum* population into phenotypic classes is a consequence of hogweed adaptation to the conditions of high cenotic richness of tall-grass communities within its native range.

In the invasive part of the range, giant hogweed grows in very favorable conditions—in the absence of tall competitors, herbivores, and pests, climatic resource limitations, distribution barriers, and anthropogenic pressure. *H. mantegazzianum* plants distribute the vitally important environmental resources across themselves. The segregation of plants into phenotypic classes with different sizes (spatial separation) and different rhythms of seasonal development (temporal segregation) made it possible to optimize the use of resources and reduce intraspecific competition in *H. mantegazzianum* populations. These factors determined the dominance of the species in the plant cover throughout the entire vegetation season.

CONCLUSIONS

In the Middle Taiga subzone of the Komi Republic, *H. mantegazzianum* plants representing different phenotypic classes differ by the start time and duration of phenological phases. The diversity of *H. mantegazzianum* phenorhythm types is determined by the specific structural and functional organization of plants belonging to different phenotypic classes and by their ability to enter secondary (summer) dormancy. Spatial and temporal segregation of plants into phenotypic classes reduces intraspecific competition in the populations of this invasive species. The seasonal developmental rhythm of self-sustaining *H. mantegazzianum* populations can be referred to as the spring–summer–autumn-green phenorhythm type with winter dormancy, which ensures the dominance of the giant hogweed over other herbaceous plants throughout the vegetation season.

Despite the phenological plasticity of *H. mantegazzianum* in different regions of its invasive range, the plants started seed dispersal when the sum of active temperatures ≥5°C (SAT5) reached the average value of 1662 ± 176°C, which accumulated over 113 ± 12 SAT5 days. SAT5 and SAT5-days values may be recommended as predictors when estimating the start of invasive hogweed diaspore dispersal period. In urban areas, the phenological phases of *H. mantegazzianum* started by 1–2 weeks earlier than in the suburbs, which should be taken into account when performing plant elimination activites.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The work does not contain any studies involving animal or human subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

Aleksandrova, M.I., Some hogweed species in the Middle-Taiga zone of the Komi ASSR, *Extended Abstract of Cand. Sci. (Agric.) Dissertation*, Kirov, 1971.

Atlas Respubliki Komi po klimatu i gidrologii (Atlas of the Komi Republic on Climate and Hydrology), Taskaev, A.I., Ed., Moscow: DiK, 1997.

Boardman, L., Lockwood, J.L., Angilletta, M.J., Krause, J.S., Lau, J.A., Loik, M.E., Simberloff, D., Thawley, C.J., and Meyerson, L.A., The future of invasion science needs physiology, *BioScience*, 2022, biac080. https://doi.org/10.1093/biosci/biac080

Borisova, I.V., *Polevaya geobotanika* (Field Geobotany), Leningrad, 1972, vol. 4, pp. 5–97.

Chadin, I., Dalke, I., Tishin, D., Zakhozhiy, I., and Malyshev, R., A simple mechanistic model of the invasive species *Heracleum sosnowskyi* propagule dispersal by wind, *PeerJ*, 2021, vol. 9, e11821. https://doi.org/10.7717/peerj.11821

Dalke, I.V. and Chadin, I.F., Modelling of *Heracleum sosnowskyi* Manden. and *Heracleum mantegazzianum* Sommier & Levier population area increase rate, *Russ. J. Biol. Invasions*, 2023, vol. 14, no. 4, pp. 509–522. https://doi.org/10.1134/S2075111723040045

Dalke, I.V., Chadin, I.F., and Zakhozhii, I.G., Agroclimatic conditions of habitats and morphometric characteristics of *Heracleum mantegazzianum* Sommier & Levier (Apiaceae, Apiales) in the Western Caucasus, *Povolzh. Ekol. Zh.*, 2026, no. 1, pp. 3–20.

Dalke, I.V., Chadin, I.F., Malyshev, R.V., et al., Laboratory and field assessment of the frost resistance of Sosnowsky's hogweed, *Russ. J. Biol. Invasions*, 2020, vol. 11, no. 1, pp. 9–20. https://doi.org/10.1134/S2075111720010026

Dalke, I.V., Maslova, S.P., Zakhozhiy, I.G., et al., Structure of cenopopulations of *Heracleum sosnowskyi* and mechanisms for maintaining their stability under northern conditions, *Russ. J. Ecol.*, 2024, vol. 55, no. 2, pp. 79–88. https://doi.org/10.1134/S1067413624020024

Dalke, I.V., Malyshev, R.V., Zakhozhiy, I.G., et al., Bet-hedging strategies in *Heracleum mantegazzianum* Sommier & Levier (Apiaceae) populations of the European Northeast Russia, *Biol. Bull. Rev.*, 2025a, vol. 15, no. 5, pp. 662–672. https://doi.org/10.1134/S2079086425700136

Dalke, I.V., Ponomarev, V.N., and Chadin, I.F., Best practices for management of invasive *Heracleum mantegazzianum* (*H. sosnowskyi*): A literature review and field application in Russia, *Izv. Komi Nauchn. Tsentra Ural. Otd. Ross. Akad. Nauk, Ser.: Eksp. Biol. Ekol.*, 2025b, no. 7(83), pp. 116–131. https://doi.org/10.19110/1994-5655-2025-7-116-131

Dudova, K.V., Dzhatdoeva, T.M., Dudov, S.V., et al., Competitive strategy of subalpine tall-grass species of the Northwestern Caucasus, *Moscow Univ. Biol. Bull.*, 2019, vol. 74, no. 3, pp. 140–146. https://doi.org/10.3103/S0096392519030039

Dvoinova, N.F. and Dudnik, E.Yu., Study of seasonal rhythmics of woody plants in urbanized territories, *Biosfera*, 2025, vol. 17, no. 3, pp. 204–212. https://21bs.ru/index.php/bio/article/view/990/0.

Ecology and Management of Giant Hogweed (Heracleum mantegazzianum), Pyšek, P., Cock, M.J.W., Nentwig, W., and Ravn, H.P., Eds., Wallingford: CAB International, 2007, p. 352.

Gioria, M., Fernández-Pascual, E., Rosbakh, S., Cruz Tejada, D.M., Dawson, W., Essl, F., Kreft, H., Lukacs, K., Pergl, J., Pinzani, L., van Kleunen, M., Wagner, M., Weigelt, P., Pyšek, P., and Carta, A., Seed germination traits reveal naturalization potential: Global insights from temperate European herbaceous species, *J. Ecol.*, 2026, vol. 114, e70223. https://doi.org/10.1111/1365-2745.70223

Gulov, D.M., Onipchenko, V.G., Martynenko, V.B., Fedorov, N.I., Logvinenko, O.A., Uzdenov, U.B., and Khubieva, O.P., Composition of aboveground phytomass of subalpine tallgrass in Teberdinsky National Park, *Byull. Mosk. O-va Ispyt. Prir., Otd. Biol.*, 2022, vol. 127, no. 5, pp. 46–53.

Heisler, G.M. and Brazel, A.J., The urban physical environment: Temperature and urban heat islands, in *Urban Ecosystem Ecology*, Aitkenhead-Peterson, J. and Volder, A., Eds., Madison: American Society of Agronomy, 2010, pp. 29–57. https://doi.org/10.2134/agronmonogr55.c2

Ji, Y., Jin, J., Zhan, W., Guo, F., and Yan, T., Quantification of urban heat island-induced contribution to advance in spring phenology: A case study in Hangzhou, China, *Remote Sens.*, 2021, vol. 13, no. 18, 3684. https://doi.org/10.3390/rs13183684

Koyushev, I.A., Characteristics and cultivation practices of Sosnowsky's hogweed (*Heracleum sosnowskyi* Manden.) and Weyrich's knotweed (*Polygonum weyrichii* F. Schmidt) in the Central Taiga zone of the Komi ASSR (using the Kortkerossky State Farm as an example), *Cand. Sci. (Agric.) Dissertation*, Syktyvkar, 1969. https://doi.org/10.5281/zenodo.11055943

Krivosheina, M.G., Ozerova, N.A., and Petrosyan, V.G., Distribution of seeds of the giant hogweed (*Heracleum sosnowskyi* Manden.) in the winter period, *Russ. J. Biol. Invasions*, 2020, vol. 11, no. 4, pp. 318–325. https://doi.org/10.1134/S2075111720040049

Krylov, A.K., Markov, A.V., and Alexandrov, Y.I., Survival of united populations in unstable environments, *Biol. Bull. Rev.*, 2021, vol. 11, no. 3, pp. 213–225. https://doi.org/10.1134/S2079086421030063

Kudinov, M.A., Kasach, A.E., Chekalinskaya, I.I., Chernik, V.V., and Churilov, A.K., *Introduktsiya borshchevikov v Belorussii* (Introduction of Hogweeds in Belarus), Minsk: Nauka i Tekhnika, 1980.

Marchenko, A.A., Biological characteristics and forage value of Sosnowsky's hogweed (*Heracleum sosnowskyi* Manden.), *Cand. Sci. (Biol.) Dissertation*, Leningrad, 1953. https://doi.org/10.5281/zenodo.10894912

Menne, M.J., Durre, I., Vose, R.S., Gleason, B.E., and Houston, T.G., An overview of the Global Historical Climatology Network-Daily database, *J. Atmos. Oceanic Technol.*, 2012, vol. 29, no. 7, pp. 897–910. https://doi.org/10.1175/JTECH-D-11-00103.1

Minin, A.A., Ananin, A.A., Buivolov, Yu.A., Larin, E.G., Lebedev, P.A., Polikarpova, N.V., Prokosheva, I.V., Rudenko, M.I., Sapel'nikova, I.I., Fedotova, V.G., Shuiskaya, E.A., Yakovleva, M.V., and Yantser, O.V., Recommendations to unify phenological observations in Russia, *Nat. Conserv. Res. Zapov. Nauka*, 2020, vol. 5, no. 4, pp. 89–110. https://doi.org/10.24189/ncr.2020.060

Otte, A. and Franke, R., The ecology of the Caucasian herbaceous perennial *Heracleum mantegazzianum* Somm. et Lev. (giant hogweed) in cultural ecosystems of Central Europe, *Phytocoenologia*, 1998, vol. 28, no. 2, pp. 205–232. https://doi.org/10.1127/phyto/28/1998/205

Ozerova, N.A. and Krivosheina, M.G., Patterns of secondary range formation for *Heracleum sosnowskyi* and *H. mantegazzianum* on the territory of Russia, *Russ. J. Biol. Invasions*, 2018, vol. 9, no. 2, pp. 155–162. https://doi.org/10.1134/S2075111718020091

Panasenko, N.N. and Kholenko, M.S., Phenology of *Heracleum sosnowskyi* in Bryansk Oblast, *Uch. Zap. Bryansk. Gos. Univ.*, 2017, no. 1(5), pp. 62–67.

Park, D.S., Huynh, K.M., and Feng, X., Phenological similarity and distinctiveness facilitate plant invasions, *Global Ecol. Biogeogr.*, 2024, vol. 33, e13839. https://doi.org/10.1111/geb.13839

Satsyperova, I.F., *Borshcheviki flory SSSR—novye kormovye rasteniya* (Hogweeds of the Flora of the USSR—New Forage Plants), Leningrad: Nauka, 1984.

Shadrin, D.M., Dalke, I.V., Zakhozhiy, I.G., et al., DNA barcode marker analysis of *Heracleum sosnowskyi* Manden. and *Heracleum mantegazzianum* Sommier & Levier (Apiaceae) from European Russia, *Russ. J. Biol. Invasions*, 2024, vol. 15, no. 3, pp. 416–431. https://doi.org/10.1134/S2075111724700309

Singh, K.K., Chen, Y.-H., Smart, L., Gray, J., and Meentemeyer, R.K., Intra-annual phenology for detecting

understory plant invasion in urban forests, *ISPRS J. Photogramm. Remote Sens.*, 2018, vol. 142, pp. 151–161. https://doi.org/10.1016/j.isprsjprs.2018.05.023

Skupchenko, L.A., *Semenovedenie borshchevika na Severe* (Seed Biology of Hogweed in the North), Leningrad: Nauka, 1989.

Spasovskii, Yu.N., Phenological and rhythm structure of phytocenoses of a northern macroslope of the Caucasus Biosphere Reserve, *Vestn. Adygeisk. Gos. Univ., Ser. 4: Estestv.-Mat. Tekh. Nauki*, 2014, no. 3(142), pp. 104–109.

Tappeiner, U. and Cernusca, A., Model simulation of spatial distribution of photosynthesis in structurally differing plant communities in the Central Caucasus, *Ecol. Modell.*, 1998, vol. 113, no. 1, pp. 201–223. https://doi.org/10.1016/S0304-3800(98)00144-6

Taylor, R., Holthuijzen, W., Humphrey, A., and Posthumus, E., Using phenology data to improve control of invasive plant species: A case study on Midway Atoll NWR, *Ecol. Solutions Evidence*, 2020, vol. 1, no. 1, e12007. https://doi.org/10.1002/2688-8319.12007

Uranov, A.A., Age spectrum of a phytocenopopulation as a function of time and energetic wave processes, *Nauchn. Dokl. Vyssh. Shk., Biol. Nauki*, 1975, no. 2, pp. 7–33.

Uranov, A.A. and Smirnova, O.V., Classification and main features of development of perennial plant populations, *Byull. Mosk. O-va Ispyt. Prir., Otd. Biol.*, 1969, vol. 74, no. 1, pp. 119–134. https://moip-bio.msu.ru/wp-content/uploads/moip_1969_074_1.pdf.

Vladimirov, D.R., Gladilin, A.A., Gnedenko, A.E., et al., *Metodika vedeniya fenologicheskikh nablyudenii* (Methodology for Conducting Phenological Observations), Moscow: Al'pina PRO, 2023.

Wolkovich, E.M. and Cleland, E.E., The phenology of plant invasions: A community ecology perspective, *Front. Ecol. Environ.*, 2011, vol. 9, pp. 287–294. https://doi.org/10.1890/100033

Zakhozhiy, I.G., Dalke, I.V., Chadin, I.F., et al., Ecogeographical analysis of the *Heracleum persicum, H. mantegazzianum*, and *H. sosnowskyi* distribution at the northern limit of their secondary ranges in Europe, *Russ. J. Biol. Invasions*, 2022, vol. 13, no. 2, pp. 203–214. https://doi.org/10.1134/S2075111722020138

Zhmylev, P.Yu., Zhmyleva, A.P., Karpukhina, E.A., and Titovets, A.V., Possible reasons of changes in seasonal plant development in connection with climate warming, *Vestn. Ross. Univ. Druzhby Narodov, Ser.: Ekol. Bezop. Zhiznedeyat.*, 2003, no. 9, pp. 98–103.

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