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POPULATION BIOLOGY OF ALLIUM AFLATUNENSE B.FEDTSCH. INTRODUCED INTO THE FOREST-STEPPE ZONE OF THE RUSSIAN FEDERATION

[1]F. Mustafa*, **[1]E.M. Oleynikova**
[1]Emperor Peter the Great Voronezh State Agrarian University, Voronezh, Russia
*e-mail: faten.mustafa.33@gmail.com

F. Mustafa* – PhD Student, Emperor Peter the Great Voronezh State Agrarian University, 1 Michurin Street, Voronezh, 394087, Russia, e-mail: faten.mustafa.33@gmail.com
E.M. Oleynikova – Doctor of Biological Sciences, Associate Professor, Professor, Emperor Peter the Great Voronezh State Agrarian University, 1 Michurin Street, Voronezh, 394087, Russia, e-mail: cichor@agronomy.vsau.ru

Abstract. The development of new green building elements and expansion of the range of ornamental plants used in landscape gardening remains a pressing issue today. In this regard, interest is growing in potential introduced species, particularly perennials, that could be used in various landscape designs. The objectives of this study included investigating the population biology of *Allium aflatunense* B.Fedtsch. during its introduction to the forest-steppe zone of the Russian Federation (Central Black Earth Region, Voronezh). *A. aflatunense* is widely used in landscape design due to its bright purple, star-shaped flowers and striking umbel-shaped inflorescence on a tall stem. After flowering, the umbels retain their ornamental value until the seeds are fully ripened. Thus, the ornamental value of the specimens is maintained throughout the entire growing season. The study was conducted from 2023 to 2025 at the B.A. Keller Botanical Garden of the Voronezh State Agrarian University. The ontogenesis and seed production of the specimens were studied. Over the three years of introduction, *A. aflatunense* plants underwent three stages and seven ontogenetic states: seed, seedling, juvenile, immature, virginal, latent generative, and young generative. The mid-life generative stage was additionally described using 10- to 12-year-old specimens. The article presents diagnostic features and biomorphological characteristics of all stages. Data on the species' seed productivity under the introduction conditions are also presented. The developmental characteristics of *A. aflatunense* grown in the forest-steppe conditions of the Central Chernozem Region suggest the success of the species' introduction and recommend it as an ornamental plant for landscaping. To initiate seed generation in specimens as early as the second year of development, vernalization of plants during the intermediate winter period should be used.

Key words: *Allium aflatunense* B.Fedtsch., introduction, ontogenesis, development period, ontogenetic state, morphological characteristics, seed productivity.

РЕСЕЙ ФЕДЕРАЦИЯСЫНЫҢ ОРМАНДЫ ДАЛА АЙМАҚЫНА ЕНГІЗГЕН ALLIUM AFLATUNENSE B.FEDTSCH ПОПУЛЯЦИЯЛЫҚ БИОЛОГИЯСЫ

[1]Ф. Мустафа*, **[1]Е.М. Олейникова**
[1]Император I Петр атындағы Воронеж мемлекеттік аграрлық университеті, Воронеж, Ресей
*e-mail: faten.mustafa.33@gmail.com

Ф. Мустафа – PhD студенті, Император Петр I атындағы Воронеж мемлекеттік аграрлық университеті, Мичурин көшесі, 1, Воронеж, 394087, Ресей, e-mail: faten.mustafa.33@gmail.com
Е.М. Олейникова – биология ғылымдарының докторы, доцент, профессор, Император Петр I атындағы Воронеж мемлекеттік аграрлық университеті, Мичурин көшесі, 1, Воронеж, 394087, Ресей, e-mail: cichor@agronomy.vsau.ru

Аннотация. Жаңа жасыл құрылыс элементтерін әзірлеу және ландшафттық бақша өсіруде қолданылатын сәндік өсімдіктердің түрлерін кеңейту бүгінгі таңда өзекті мәселе болып қала береді. Осыған байланысты әртүрлі ландшафттық дизайндарда қолданылуы мүмкін

әлеуетті енгізілген түрлерге, әсіресе көпжылдық өсімдіктерге қызығушылық артып келеді. Бұл зерттеудің мақсаттарына *Allium aflatunense* B.Fedtsch популяциясының биологиясын зерттеу кірді. Ресей Федерациясының орманды дала аймағына (Орталық Қара Жер аймағы, Воронеж) интродукциясы кезінде *A. aflatunense* ландшафт дизайнында кеңінен қолданылады, себебі ол ашық күлгін, жұлдыз тәрізді гүлдері және биік сабақтағы таңғажайып қолшатыр тәрізді гүлшоғыры. Гүлденгеннен кейін, қолшатыр тұқымдары толық піскенше сәндік құндылығын сақтайды. Осылайша, үлгілердің сәндік құндылығы бүкіл өсу кезеңінде сақталады. Зерттеу 2023 жылдан 2025 жылға дейін Воронеж мемлекеттік аграрлық университетінің Б.А. Келлер атындағы ботаникалық бағында жүргізілді. Үлгілердің онтогенезі және тұқым өндірісі зерттелді. Интродукцияның үш жылында *A. aflatunense* өсімдіктері үш кезеңнен және жеті онтогенетикалық күйден өтті: тұқым, көшет, жас, жетілмеген, тың, жасырын генеративті және жас генеративті. Орташа генеративті кезең 10-12 жастағы үлгілерді пайдаланып қосымша сипатталды. Мақалада барлық кезеңдердің диагностикалық ерекшеліктері мен биоморфологиялық сипаттамалары келтірілген. Интродукция жағдайында түрдің тұқым өндірісі туралы деректер де келтірілген. Орталық Чернозем аймағының орманды-дала жағдайында өсірілген *A. aflatunense* өсімдігінің даму ерекшеліктері түрдің интродукциясының сәттілігін көрсетеді және оны көгалдандыру үшін сәндік элемент ретінде ұсынады. Дамудың екінші жылында үлгілерде тұқым өндіруді бастау үшін, аралық қысқы кезеңде өсімдіктердің вернализациясын қолдану керек.

Кілт сөздер: *Allium aflatunense* B.Fedtsch., интродукция, онтогенез, даму кезеңі, онтогенетикалық кезең, морфологиялық сипаттамалары, тұқым өндіру.

ПОПУЛЯЦИОННАЯ БИОЛОГИЯ *ALLIUM AFLATUNENSE* B.FEDTSCH ПРИ ИНТРОДУКЦИИ В ЛЕСОСТЕПНОЙ ЗОНЕ РОССИЙСКОЙ ФЕДЕРАЦИИ

[1]Ф. Мустафа*, **[1]Е.М. Олейникова**

[1]Воронежский государственный аграрный университет имени императора Петра I, Воронеж, Россия

*e-mail: faten.mustafa.33@gmail.com

Ф. Мустафа – аспирант, Воронежский государственный аграрный университет имени императора Петра I, улица Мичурина, 1, Воронеж, 394087, Россия, e-mail: faten.mustafa.33@gmail.com

Е.М. Олейникова – доктор биологических наук, доцент, профессор, Воронежский государственный аграрный университет имени императора Петра I, улица Мичурина, 1, Воронеж, 394087, Россия, e-mail: cichor@agronomy.vsau.ru

Аннотация. Разработка новых элементов зеленого строительства и расширение ассортимента декоративных растений, используемых в ландшафтном озеленении, остается актуальной задачей сегодняшнего дня. В связи с этим возникает интерес к потенциальным интродуцентам, прежде всего многолетним, которые могли бы использоваться в различных вариантах ландшафтных композиций. В задачи исследований данной работы входило изучение популяционной биологии *Allium aflatunense* B.Fedtsch. при интродукции вида в лесостепной зоне Российской Федерации (Центрально-Черноземный регион, город Воронеж). *A. aflatunense* широко используется в ландшафтном дизайне благодаря ярко-лиловой окраске цветков звездчатой формы и эффектному соцветию в виде зонтика на высоком цветоносе. После цветения зонтики сохраняют свою декоративность вплоть до полного созревания семян. Таким образом, декоративность особей обеспечивается в течение всего вегетативного периода. Исследования проводились 2023-2025 гг. в Ботаническом саду имени Б.А. Келлера Воронежского государственного аграрного университета. Был изучен онтогенез и семенная продуктивность особей. За три года интродукции растения *A. aflatunense* прошли три периода и семь онтогенетических состояний: семя, проросток, ювенильное, имматурное, виргинальное, скрытогенеративное и молодое генеративное. Средневозрастное

генеративное состояние дополнительно описано на особях 10-12-летнего возраста. В статье приводятся диагностические признаки и биоморфологические характеристики всех состояний. Представлены данные по семенной продуктивности вида в условиях интродукции. Особенности развития *A. aflatunense* при выращивании в условиях лесостепи ЦЧР позволяют сделать вывод об успешности интродукции вида и рекомендовать его как декоративный элемент зеленого строительства. Для начала генерации у особей уже на второй год развития следует использовать яровизацию растений в промежуточный зимний период.

Ключевые слова. *Allium aflatunense* B.Fedtsch., интродукция, онтогенез, период развития, онтогенетическое состояние, морфологические характеристики, семенная продуктивность.

Introduction. The introduction of new plant species is currently in demand not only for fruit and for vegetable crops but also for ornamental plants, which are considered one of the most important elements of modern urban landscape design. Characterizing the ontogenesis of an introduced species in a new habitat is key to its successful use for various purposes. The development of new landscaping elements and expanding the range of ornamental plants used in landscape design remains a pressing task today. Therefore, interest is growing in potential introduced species, particularly perennials, which could be used in a variety of landscape compositions. We consider *Allium* L. to be one of the most promising genera, as various onion species possess a number of distinct advantages: they are highly decorative, early-flowering species, yet retain their attractiveness for some time after seed maturation, remain in a generative state for a long time, and have flowers of varying heights and shades, allowing them to be used in compositions of varying scale and content.

Material and methods. The object of our study is the onion (*Allium aflatunense* B.Fedtsch., family *Liliaceae*), belonging to the genus Allium L., subgenus *Melanocrommyum*, section Porrum Don (Cheremushkina, 2004:280). *Allium aflatunense* is a perennial bulbous plant. It grows in the middle and upper mountain belts of Central Asia and is endemic to the Tien Shan. It is a xeromesophyte (Bukharov et al., 2022:16-24). Currently, collecting this species from the wild is strictly prohibited. In addition to its high ornamental value, the plant has medicinal properties and can be used as a food and honey plant (Gamedzhieva et al., 2021:97-101).

The aim of this study is to describe the main stages of onion development over three years of introduction and to evaluate the seed productivity of the species in the Voronezh Region of the Russian Federation. Introduction work is being conducted at the B. A. Keller Botanical Garden of the Voronezh State Agrarian University named after Emperor Peter I from 2022 to 2025. The planting material consists of *A. aflatunense* seeds obtained through an exchange program from the Botanical Garden of Ivanovo State University. Sowing took place in a closed greenhouse on 15 March 2023, in a substrate with equal proportions of sod soil, peat, and river sand. The seeds were not pre-treated. Gradual acclimatization and transfer of plants to an open environment were synchronized and depended on the developmental stage. Seedlings and young plants were grown in a closed greenhouse at a temperature of 20-25°C. Watering was carried out twice a week, as the initial stages of development are most sensitive to unfavorable factors. As the plants reached maturity (virginal ontogenetic stage), they were transferred to a semi-open greenhouse for protection from strong direct sunlight in the summer and winds in the fall. In winter, they were covered with a 20 cm thick layer of snow.

At the beginning of the following spring (2024), the plants were transferred to permanent soil in experimental plots. The botanical garden's experimental plot is composed of leached chernozem on loess-like loam, medium-deep, heavy loamy, and low-humus soil. The humus content in the 0-20 cm layer does not exceed 3.7-3.8%, the pH is 5.0-5.2, and the hydrolytic acidity is 3.20-3.35 mg-eq per 100 g of soil. The content of mobile phosphorus is 100-105 mg/kg, exchangeable potassium is 105-128 mg/kg (Gladysheva&Oleynikova, 2016:198).

The methodological basis of the study was the traditional methods of population biology and phenology, repeatedly adapted to the conditions of the Central Black Earth Region (Zhukova, 1995; Oleynikova, 1999). The ontogenetic states of the species were identified using the terms and characteristics proposed by T.A. Rabotnov, A.A. Uranov and their students, who stood at the origins of the Soviet population school (Vorontsova et.al., 1976). According to their research, individual plant

development can be divided into 4 periods and 10-12 ontogenetic states. **1. Latent period** (dormant seeds - ***se***). **2. Pregenerative period** (sprouts- ***p***, juvenile - ***j***, immature - ***im*** and virginile (young vegetative) - ***v*** ontogenetic states). **3. Generative period** (latent generative - g_0, young generative - g_1, middle-aged (mature) generative - g_2, and old generative - g_3 ontogenetic states). **4. Post-generative period** (subsenile - ***ss***, senile - ***s***, and subcadaveric - ***sc*** ontogenetic states). It should be noted that it is not always possible to distinguish all of these ontogenetic states in specific species; the spectrum of ontogenetic states can vary significantly among different species, reflecting species-specific features of their biology and individual development.

Seed productivity under introduction conditions was determined using generally accepted methodological developments (Vainagiy, 1974; Oleynikova, 2007).

Results and discussion. We described the ontogenesis of *A. aflatunense* for the first time for the forest-steppe of the Central Chernozem Region (Fig. 1-2, Table 1-2). Over three years of introduction, *A. aflatunense* passed through 7 ontogenetic states in its development. In the first year, the following states were observed: *se*, *p*, *j*, *im*, and *v*. The second year of development began with a latent generative ontogenetic state, which successively transitioned to a young generative one. In the third growing season, the capacity for generation was preserved, and the g_1 state continued. The middle-aged generative state g_2 was observed in previously introduced *A. aflatunense* plants at the age of 10-12 years. States g_3, *ss*, *s*, and *sc* were not recorded on the accessions planted by us or previously. The identified ontogenetic states have the following diagnostic features.

I. Latent period. Seed (*se*). The seeds are matte black, round, and warty-surfaced. Their diameter is 1-2 mm. Under natural conditions, the seeds ripen in capsules ranging from broadly ovoid to spherical, 4-5 mm in diameter.

II. Pregenerative period. Sprouts (*p*). sprouts emerged on the sixth day or later. Germination was low, reaching only 32.5%. According to literature data (Fomina, 2021:180-190), this is due to deep seed dormancy in species belonging to the subgenus *Melanocrommyum*, including *A. aflatunense*. Dormancy can be partially overcome by dry storage or cold stratification. The seedling is no more than 7 cm tall (Fig. 1). The cotyledon is single, approximately 1 mm wide, elliptical, and has a thin rootlet. The upper part of the cotyledon, initially curved like a loop, then gradually straightens. Reaching the maximum seedling length is accompanied by the appearance of new leaves, heralding the onset of the next stage. Stage (p) lasted 2 weeks under our conditions. After this, the cotyledons began to dry out until they died completely in mid-April, while remaining attached to the plant.

Table 1. Biometric parameters of *A. aflatunense* in the pregenerative period

Parameters	Ontogenetic states			
	p	***j***	***im***	***v***
Number of leaves (pcs.)	1	2.5 ± 0.5	3.2 ± 0.4	3.7 ± 0.7
Leaf length (cm)	6.8 ± 0.9	12.8 ± 1.4	19.5 ± 1.9	29.5 ± 3.2
Leaf width (cm)	0.1	0.1	1.5 ± 0.3	2.2 ± 0.5
Number of adventitious roots (pcs.)	-	4.1 ± 0.8	11.7 ± 2.2	18.7 ± 3
Bulb diameter (cm)	-	0.5 ± 0.1	0.7 ± 0.1	1.1 ± 0.3

Juvenile (*j*) - This ontogenetic state lasts approximately 2 months (from early April to late May of the first year of introduction). State *j* is characterized by immature traits and properties inherent to adult plants. The plant is a small, single-shoot, rosette shoot consisting of several rounded leaves. Maximum plant height is recorded at the end of April (Fig. 1). During the transition to the juvenile state, the main root is replaced by weak, fibrous adventitious roots, and bulb development is not observed. By early summer, the leaves begin to yellow and are replaced by new leaves, morphologically distinct from the previous ones. Complete death of the leaves in state *j* occurs in mid-May.

Immature (*im*) - the transitional state from juvenile plants to adult vegetative ones. Plants are also single-shoot, but with leaves characteristic of the species. The leaves are long, narrowly linear, and their number does not exceed three. The root system is more developed, and small bulbs are beginning to form. In our protected conditions, the *im* stage was short-lived, lasting no more than a month. Soon, larger, wider leaves appeared, replacing the yellowing ones, and the plants became taller and denser.

1 **2** **3**

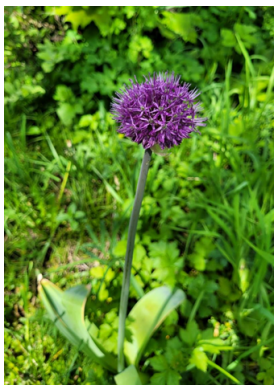
Fig. 1. *Allium aflatunense* plants in the pregenerative stage of ontogenesis: 1 - seedling; 2 - juvenile; 3 - bulb of a virginal plant

Virginal (*v*) is the final ontogenetic state of the pregenerative period (Fig. 1, Table 1). The transition of individuals to the *v* state began in mid-July and continued until the end of summer in the first year of introduction (until the end of the growing season). Plants are characterized by long linear leaves, become larger and denser, and form small bulbs up to 4-5 mm in diameter. With the onset of autumn, vegetation ceases, the aboveground portion begins to yellow, and the bulbs enter a dormant state until the next growing season. Complete death of the aboveground portion occurs in mid-November. Overwintering took place in a semi-open greenhouse; plants were protected by a 20 cm thick snow cover to reduce the negative impact of low temperatures on the formed bulbs.

III. Generative period. Latent-generative state (g_0). Under the conditions of the introduction experiment, plants entered the generative period in the second year of introduction. In early spring, during the first ten days of March, the rosette shoot begins to grow, and simultaneously, the latent generative stage begins. Mature plants are represented by vegetative specimens with 3-4 linear leaves

(Table 2). The g_0 stage lasts approximately two months, until early May. Morphologically, g0 plants are similar to virginal specimens, but the bulb structure is significantly different. With the onset of vegetation, a generative bud is formed between the fleshy scales of the bulb and then begins to grow, forming the future inflorescence and flower stalk. We believe that under the conditions of the introduction experiment, it was vernalization during the first wintering that facilitated the onset of generation in the second growing season. Literature data indicate that, under natural conditions, most onions initiate generative development at least two years before flowering (Cheremushkina, 2004:280). The transition to the young generative stage is marked by the appearance of a flower stalk in the center of the rosette shoot. It begins to grow rapidly and bears the rudiments of the inflorescence above the soil surface.

Young generative state (g_1). Plants are single-shoot, the height of the inflorescence is up to 30 cm, exceeds the length of the leaves by about 1.5 times (Fig. 2, Table 2). At the top of the stalk, the inflorescence opens - a dense spherical umbel, consisting of numerous purple star-shaped flowers. The leaves are linear or strap-shaped, long, up to 4 on each shoot. The flowering period lasts about two weeks, until the middle of the third ten-day period of May. Pollination is cross-pollination by insects. The fruit is a dehiscent capsule. Initially, 6 ovules are laid in the ovary of the pistil of each flower (Mustafa, Oleynikova, 2024: 94-98), 1-2 seeds are formed in a mature capsule. Ripening of seeds occurs in the second-third ten-day period of June, complete death of the above-ground part in August. The silhouette of the drying umbel retains its decorative appearance, so faded plants can be kept in flowerbeds until the seeds have sprung, that is, until the first or second ten days of July. The high ornamental value of flowering and faded *A. aflatunense* plants makes them very attractive for use in landscape gardening.



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2

Fig. 2. Middle-aged generative state of *A. aflatunense*: 1 - General appearance of specimen; 2 - Umbel-shaped inflorescence during the period of mass flowering. 15 May 2023, experimental plot of the Botanical Garden of the Voronezh State Agrarian University

Middle-aged generative state (g_2) - To describe the g_2 state, plants previously introduced to the Botanical Garden of the Voronezh State Agrarian University were used. Their age is 10-12 years. Our observations suggest that the transition to the g_2 state occurs in the 4th-5th year of the generation, that is, no earlier than 5 years of calendar age under the conditions of introduction. The middle-aged generative state is characterized by maximum development of vigor and seed productivity of individuals; greater stability of biometric indicators across years should also be noted (Table 2).

Table 2. Biometric parameters of *A. aflatunense* in the generative period

Parameters	Ontogenetic states					
	g_0	g_1		g_2		
		2024	2025	2023	2024	2025
Number of leaves (pcs.)	3.2 ± 0.6	3.5 ± 0.5	5.9 ± 1.1	9.5 ± 1.6	9.2 ± 2.1	10.2 ± 1.7
Leaf length (cm)	24.1 ± 4.4	25.8 ± 3.7	36.4 ± 2.7	51.3 ± 5.0	54.8 ± 3.7	53.0 ± 3.7
Leaf width (cm)	1.7 ± 0.4	2.1 ± 0.5	2.7 ± 0.4	5.3 ± 0.7	5.2 ± 0.5	5.4 ± 0.6
Average length of flower stalk (cm)	-	29.3 ± 3.7	50.5 ± 7.1	103.2 ± 9.8	106.8 ± 11.1	105.7 ± 9.0
Average diameter of flower stalk (cm)	-	1 ± 0.2	1.2 ± 0.2	1.5 ± 0.1	1.4 ± 0.1	1.4 ± 0.2
Average diameter of inflorescence (cm)	-	2.8 ± 0.8	2.9 ± 0.5	4.7 ± 0.6	4.9 ± 0.6	4.8 ± 0.5

A. aflatunense plants have two to four flower stalks over 1 m tall. large inflorescences up to 5 cm in diameter. and up to 200 or more flowers per inflorescence. Seed production indicators were also determined using these model plants (Table 3). During the work. the number of flowers. fruits and seeds in the fruit was calculated per one elementary inflorescence - umbrella (Fig. 3). Actual seed production. fruiting percentage. and productivity coefficient were statistically determined (Table 3).

The set seeds fully mature. which is one of the main criteria for the successful introduction. The values of absolute indicators of seed productivity - the coefficients of fruit formation and seedification - are on average 93% and 45%. respectively (Mustafa, Oleynikova, 2024) - indicate good prospects for growing *A. aflatunense* seed material in the conditions of the Voronezh region.

Fig. 3. Mature fruit buds, fruits and seeds of *A. aflatunense*

To characterize the seed production of plants and subsequently evaluate the success of their introduction. it is necessary to understand the structure of the generative organs of the species under study. in particular. the structure of the ovary and the number of ovules. Since comparative embryological analysis has become an important method of plant taxonomy in recent decades. we were able to find literature data on this issue. In most onion species of the subgenus *Melanocrommyum*. the superior ovary has two three-locular ovules. from which up to six seeds develop (Hanelt. 1992; Fritsch. 2001). Microscopic analysis of flowers confirms that the flowers of *A. aflatunense* have a similar structure. Considering that each simple umbel produces. on average. over 200 flowers. we can

speak of high rates of seed production - both potential and actual. The set seeds ripen fully. which is one of the main criteria for the success of their introduction. The values of absolute indicators of seed productivity - the coefficients of fruit formation and seeding indicate good prospects for growing *A. aflatunense* seed material in the conditions of the Voronezh region.

Table 3. Characteristics of seed productivity of *A. aflatunense*

Показатели семенной продуктивности	**Value**
Number of umbels per plant (pcs.)	1
Number of ovules per flower (pcs.)	6
Number of flowers per inflorescence (pcs.)	211.67
Number of fruits per inflorescence (pcs.)	198.33
Number of seeds per fruit (pcs.)	2.94
Fruit formation coefficient (%)	93.70
Seed productivity: potential/actual	1270.02/583.09
Productivity coefficient (%)	45.91

Conclusion. Based on the research conducted in the forest-steppe conditions of the Voronezh region. the successful introduction of *A. aflatunense* can be confirmed. Individuals sequentially passed through three periods and seven ontogenetic states. Rapid development during the pre-generation period (individuals passed through five states in one growing season) is explained by cultivation in protected conditions and the absence of competition from other species. The transition to generation as early as the second year of vegetation is attributed to vernalization. which individuals underwent during the intermediate winter period. Favorable external conditions stimulated plant development during the most sensitive period of ontogenesis. High seed productivity and the maturation of viable seeds also indicate the success of the species introduction. The generative development of *A. aflatunense* plants already in the second year under the conditions of introduction. the decorativeness of individuals at the time of flowering and seed ripening allows the use of this species in landscaping both in small architectural forms and in large landscape compositions in parks. squares and other public spaces.

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