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Humans as Regulators of Plant–Herbivore–Insectivore System in the Urban Environment

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Abstract—Man affects the sanitary and decorative state of urban plantations by carrying out various agrotechnical measures, in particular topiary. The human activity was shown to affect the members of the plant–herbivore–insectivore system in different ways. The agrotechnical measures positively affect humans and plants and negatively, phytophagous and entomophagous insects. The spatial and temporal changes in the urban environment are responsible for different microsuccessions in colonization of plants by insects.

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The ecological efficiency of natural complexes in urban territories depends on two main factors: their area and their biodiversity, first of all, the diversity of the plant community which determines that of heterotrophic organisms (Edrenkina, 2005).

An important place in the fauna of urban ecosystems belongs to insect complexes in whose trophic structure herbivores prevail (Kiselev, 2005). The city is a specific environment for phytophagous insects. On the one hand, the lower level of antibiosis of the food plants due to urban stresses and a weaker influence of parasites and predators facilitate population growth of the insectivores. On the other hand, their abundance is negatively affected by the "insular" structure of urban plantations and the direct and indirect (via the food plant) action of pollutants (Tarasova, 2004).

Of special danger for trees and shrubs in urban plantations are phyllophagous insects. This is especially true of aphids (Aphidoidea), which are capable of fast colonization and utilization of food resources due to their parthenogenesis and rapid development (Dyakonov, 2003). Aphid faunas of some Russian cities count tens of species, for instance, there are 68 aphid species in Voronezh (Kuz'minov, 2005). Aphids usually live in colonies on the lower side of leaves, on young shoots and pedicles, feeding on plant sap. They weaken the plant, reduce its disease resistance, and may act as vectors of viral diseases (Shcherbakova and Karpun, 2008). The urban monospecific plantations growing compactly are especially easily damaged by quickly reproducing aphids.

Pollution, first of all, atmospheric one, is of certain significance for the urban biota (Tarasova, 2004). For example, a layer of dust covering leaves makes them unattractive for insects with chewing mouthparts but not for those with piercing-sucking mouthparts (Barannik, 1979); the latter group is particularly resistant to air pollution resulting from industry and transport. Therefore the aphid population density in trees growing in city streets is much higher than that in suburban areas or large forest parks; in turn, abundance of predators and parasites of aphids increases correspondingly. However, due to the sucking mouthparts, aphids can feed only on sappy parts of plants with the thin epithelium. As the food plant grows and develops, aphids have to move onto younger leaves of lateral and auxiliary shoots. Strongly lignified branches with rough bark are not colonized by aphids, only young shoots of the current year being vulnerable.

Different species of dog rose are used in landscaping of streets, gardens, and parks, the Ramanas rose *Rosa rugosa* Thunberg, 1784 and the cinnamon rose *Rosa davurica* Pallas, 1789 being regarded as the most resistant to gaseous pollution (Zei-Nechaeva, 1984). Aphids are common pests of the dog rose in cities (Kolesnikov and Boldyrev, 2007). For example, the insect fauna of the dog rose in the artificial ecosystems of Ufa includes 21 species: 17 phytophagous and

4 entomophagous (Zei-Nechaeva, 1984). The rose aphid *Macrosiphum rosae* (L., 1758) and the strawberry aphid *Capitophorus tetrarhodus* (Walker, 1849) are regarded as potential pests in European Russia. The species are considered to be focal pests, their harmfulness not exceeding 5% (Kolesnikov and Boldyrev, 2007).

Most of the works devoted to the study of the triotroph system "plant–herbivore–insectivore" consider its biochemical aspects, such as the influence of metabolites of the food plant on herbivores and through them, on parasites (Martemyanov and Bakhvalov, 2007). Much less attention is devoted to agrotechnical methods (in a broad sense, i.e., as applied not only to soils but also to vegetation and animals) in spite of their important role in protection of green plantings. For example, practically all the aphid species overwinter on shoots in the tree bark fissures whence they disperse onto new leaves in spring; correspondingly, old and unthinned plantations with withered branches are sources of aphid infestation, whereas periodical pruning of such branches undermines the food supply of aphids. In some cases, outbreaks of urban plant pests result from mistakes in technology and timing of cultivation and protection of plants. Periodical trimming of trees and shrubs, rejuvenation of old plantations, treatment of the soil, etc. are carried out in order to control the insect populations. Management of green plantings also affects the groups of associated organisms, i.e., those using the plants as food or a habitat.

In the present work, we shall consider the influence of agrotechnical trimming on a "plant–herbivore–insectivore" triotroph system.

MATERIALS AND METHODS

The study of human impacts on a "plant–herbivore–insectivore" triotroph system will be carried out by the example of the influence of dog rose trimming on herbivores and their predators.

The material was collected in the city of Ufa (Bashkortostan). Phenological observations of the insectivore were carried out since 2000, and those of the triotroph system, in 2008–2009, in the south part of the city. The quantitative data were collected in the June of 2009, in a model plot: a lawn about 100 m long and 8 m wide located between the sidewalk and the roadway on the even side of Pushkin Street, at the corner of Aksakov Street.

The Ramanas rose *R. rugosa* was studied as an autotrophic component of the triotroph.

The dog rose shrubs were planted in a linear fashion along the pavement; the initially complete hedge (0.8–1.5 m wide) with time became fragmented with gaps of 0.3–1.5 m. Shrubs are trapezoid, smoothly widening from 70 cm at the base to 110–130 cm at the cut line. Branching starts at a height of 50–80 cm. The base of the shrubs is positioned 20 cm from the asphalt.

The rose aphid *M. rosae* was chosen as a herbivore component. In Ufa, this species is considered to be the most important pest, together with the tip-infesting sawfly *Ardis brunniventris* (Hartig, 1837), the rose-infesting fruit fly *Rhagoletis alternata* (Fallen, 1814), and 5 species of leaf-roller moths (Zei-Nechaeva, 1984).

The two-spot ladybird *Adalia bipunctata* (L., 1758) (Coleoptera, Coccinellidae) was studied as an insectivore. This was the most abundant of the 10 ladybird species recorded by us on the dog rose. The adults observed were mostly of the common morph (typica), with the red background and two black spots on elytra; black forms (sexpustulata and quadrimaculata) were rare (less than 4%). The larval stages were differentiated into two groups: young (I–II) and old (III–IV instars) according to Savoiskaya (1983).

On the first observation day we caught the process of trimming dog roses: the western part of the plot had been already finished, the eastern part, not yet. First we examined the untrimmed (intact) part of the shrubs, then the trimmed one. On subsequent days observations were carried out daily. Untrimmed dog rose plantations within a house block were studied as controls.

All the quantitative data on insects are given per one linear meter of the hedge.

RESULTS

Intact shrubs. The phenology of the dog rose in Ufa is as follows: foliation in the second decade of May, florescence in the third decade of May–the second decade of June, the beginning of fruit ripening in the third decade of June.

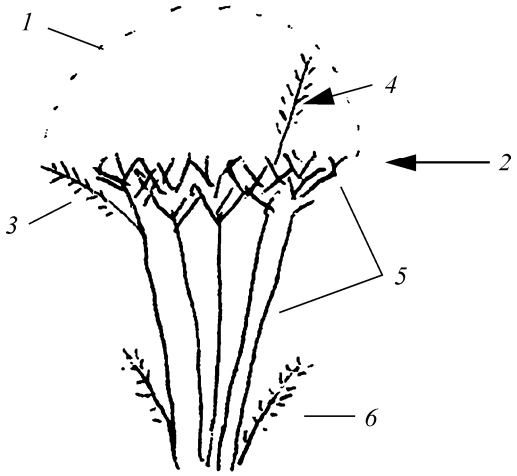
The herbivore. The aphids inhabited 15–25% of young (non-skeletal) shoots of the dog rose. The aphids feed on the dog rose from the second decade of May to the second decade of August, developing up to 10 generations per season.

The insectivore. Under the conditions of the South Urals, *A. bipunctata* is bivoltine; the first generation develops on the dog rose. Oviposition starts from the first decade of June, larvae appear from the second decade of June, adults of the second generation, in the third decade of June.

All the stages of development of the insectivore *A. bipunctata* were discovered in the model plot. The density of adults was 4–8 ind./m; they concentrated on the young shoots, occasional individuals moving to the skeletal branches in search of food. The density of eggs was 0.6 ind./m. Clutches were located on the lower side of the leaves of young shoots. The density of larvae was 4.4 ind./m. Larvae of different instars were found only on young shoots but not on skeletal branches. About one third of the larvae observed were eating aphids, the rest were walking. The pupae (0.8 ind./m) were located on the distal (upper) third of young shoots.

Trimmed shrubs. The dog rose is a shrub whose renewal after trimming occurs by large side shoots. The ornamental and sanitary trimming of trees and shrubs carried out in the city includes flat trimming: all the vertical shoots are cut off on top, at a height of 0.5–1.5 m from the ground, and also on the sides, to obtain the desired transverse profile. In the observation plot, the dog rose is trimmed flat at a height of 1.4–1.6 m, leaving stout main skeletal branches on which shoots of the next orders are subsequently formed. It is advised to remove and immediately burn the cut branches on completion of trimming (Serebryakova et al., 1977).

In the annually trimmed shrubs, one can distinguish strongly lignified perennial branches (here, they are referred to as "skeletal") extending from the ground to the trim plane; and weakly lignified shoots growing after annual trimming ("young"). Since shrubs are trimmed in Ufa in the middle of every summer, the shoots which appeared at the end of the preceding warm season (June–September) and at the beginning of the current one can be regarded as young ones. Shoots 20–50 cm long are removed and only skeletal branches without young shoots and leaves are left. Single shoots remaining along the periphery of the shrub (short of the trimming plane) and above the shear plane (overlooked during trimming) will be referred to "side" and "occasional" ones (figure). The cut-off shoots are piled at the base of the shrub, on both sides of the hedge, including asphalt.



The dog rose shrub after ornamental trimming: the outline of branches before trimming (*1*), the flat trimming level (*2*), "side" shoots (*3*), "occasional" shoots left after trimming (*4*), skeletal branches (*5*), and "basal" shoots (*6*).

The herbivore. No aphids were found on the shrubs after trimming. Removal of young shoots considerably lowered the number of aphids remaining on the dog rose; only single individuals may remain on "occasional" shoots. In hot weather the cut-off shoots dry quickly. Although wingless aphids can theoretically move as far as 10–18 m away from the primary plant within a day (Dyakonov, 2003), in our case most of the aphids continued to feed on the cut shoots (until they dried out completely), and within this period the ladybird larvae located on the same shoots managed to exterminate the aphids. Part of the winged aphids flew away.

The insectivore. The density of **adults** was 0.1 ind./m. In the process of trimming the disturbed beetles fall to the ground or fly away. Only occasional adults were found on the already trimmed shrubs, most of the beetles having left the plot or flown (single individuals) to the intact part of the plantation. On the subsequent days only occasional adults were recorded (2–3 for the whole plot).

Eggs. No clutches of the insectivore were found on skeletal branches or on "occasional" (overlooked) shoots.

A few **larvae** were found only on side and "occasional" shoots, with a density of 0.2 ind./m. Some larvae fell to the ground during trimming due to mechanical impact; others fell to the ground together with the cut-off shoots and did not leave them. No larvae were found either on the asphalt or on the grass beyond the cut shoots. Subsequent observations showed

that larvae remained on the same branches and finally perished having consumed all the available aphids: younger predator instars died before older ones.

Larvae from the shoots fallen to the asphalt were affected by high temperatures and moved very actively on a cut-off shoot. However, they did not pass over from the shoot on to the asphalt (3 observations, each 15 min long), even if they were "urged" to do so. Their motor activity was short-term; after a period of intensive chaotic movement the larvae stopped, contracted, and remained motionless (moving off only when pushed). The larvae on the shoots fallen to the asphalt died in 20–40 min. Two old larvae taken off the shoot and put on the asphalt moved chaotically and actively but then stopped and died in 25–30 s due to heat shock (the temperature at the time of the experiment was over 30°C and that of the asphalt was even higher). In another experiment, when old larvae were "offered" transition to another substrate (a plantain leaf picked close to the hedge or other dog rose shoots; the substrates were positioned in the same plane before the larva), 3 out of 4 larvae tested passed over.

No **pupae** were found on the shrubs after trimming.

DISCUSSION

Ornamental trimming of shrubs negatively affects the preimaginal stages of ladybirds. Especially catastrophic are its consequences for the egg clutches. Since the shrubs are quite thoroughly trimmed (one overlooked shoot per shrub), the clutches are completely destroyed: no eggs were found on any "occasional" shoot. Given the equal distribution of clutches among all the young shoots, the probability of survival of eggs that remain by chance on an isolated shoot will be low since such shoot is open to sun, wind, and mechanical damage. Larvae hatching under such conditions are doomed to starvation (due to lack of aphids) and cannot complete their development. The eggs on the fallen shoots also have no chance for successful development. Even though the cut-off shoots were not removed but remained on the ground for at least two weeks, both eggs and larvae of ladybirds perished.

Our assumption that the larvae could move back to the shrub from the cut-off shoots and complete development was not confirmed. First, they were not observed to leave the fallen branches; second, it would be difficult for them to get to the shrub and find suitable (non-skeletal) shoots; third, the food objects (aphids) are too scarce on the trimmed shrub.

The mature pupae can theoretically complete development but this possibility diminishes rapidly if they remain on the ground, among the drying cut-off shoots.

Specialists admit the usefulness of sanitary and ornamental trimming, emphasizing the need to remove the nourishing and basal shoots on which aphid eggs mostly overwinter. Moreover, to avoid infestation of healthy plants it is advised to burn the cut shoots before hatching of winged females (the dispersal stage) (Kuzmin, 2005). Although ornamental trimming improves the sanitary state and appearance of the shrub and provides an effective means of aphid control, its resulting action upon the abundance of insectivores should be considered as negative. The reason is not only the destruction of aphids as the food source for insectivores (after all, it improves the health of the shrub), but also direct elimination of eggs, larvae, and partly pupae of insectivores.

The influence of agrotechnical measures on the food plant is also ambivalent: are there more advantages or disadvantages in the trimming? For the dog rose it is an advantage (rejuvenation and riddance of pests); for the aphids, it is a disadvantage (death and loss of the trophic base); for insectivores, it is a disadvantage (death of preimaginal stages and loss of the trophic base); for humans, it is an advantage (a healthy and attractively looking hedge). The concerns of the citizens should not be ignored either: the city is first of all a human habitat, therefore all the measures for optimization and control of its natural components should be directed at creating comfort conditions. On the whole, in our opinion, advantages prevail, since the primary task of forming a healthy and ornamental hedge is fulfilled; simultaneously, the abundance of pest is controlled. In choosing between maintaining a high abundance of insectivores and maintaining healthy and attractively looking plantations, preference should be given to the latter.

Let us also try to "justify" the involuntary harm done to insectivores. Aphidophagous ladybirds regularly face the instability of the trophic base in nature (Yablokov-Khnzoryan, 1976), since their development cycle is too long to follow the fluctuations of the aphid abundance. Under natural conditions, there are frequent cases when part of the ladybird generation fails to complete development before the food objects disappear. Therefore, in our situation there is nothing "critical" for ladybirds, which is indirectly supported

by the high abundance of this family in cities, especially of the anthrop two-spot ladybird.

Low efficiency of ladybirds as biological control agents noted in some cases is determined by their inability to stop the early (May) outbreak of aphids (see Chenikalova et al., 2008): the number of overwintered ladybirds is not great, whereas larvae, the most voracious stage, have not yet hatched from the eggs laid at the end of spring. The development of aphids is much faster, being completed within 5–7 days from the egg to the adult (in the two-spot ladybird development lasts about 30 days, in others, even longer); an almost 8-fold increase in reproductive potential is achieved due to parthenogenesis, as compared with bisexual insects of similar size (Dyakonov, 2006). The sucking mode of feeding is very efficient and allows a considerable part of the energy obtained to be spent on reproduction. Due to this, the aphids reproduce fast and do great harm to plants. Thus, earlier terms of trimming should be recommended (for instance, the end of April–the beginning of May), which would allow adult ladybirds to lay eggs on the newly grown young shoots. Such terms are also recommended by agrotechnicians: for better growth of the shoots, dog rose in the temperate zone of Russia should be trimmed during the period of relative rest, namely in autumn (September–October) or in spring (March–April) (Serebryakova et al., 1977).

It should be noted that the shrubs within the house blocks are trimmed irregularly or not trimmed at all. The heterotrophs inhabiting intact dog rose shrubs developed in the ordinary course, the mass hatching of ladybird larvae occurring in mid-June.

The timing of agrotechnical measures is of great importance; however, due to irregular financing, they are carried out at different times throughout the vegetative season, with the receipt of funds (the city plantations are maintained by the municipal organization "Gorzelenkhoz"). This results in the non-simultaneous trimming throughout the season, in different years, and in different parts of the city where intact islands of in-block plantations remain. In this way, agrotechnical disruptions seem to be shifting in place and time (similar to the gap mosaic concept: Korotkov, 1991). With the passage of time, young shoots growing after trimming restore the disturbed habitats making them suitable again for herbivores and then for insectivores. This heterogeneity allows mobile insects (including both aphids and ladybirds) to migrate between localities at different stages of restoration, using in-block intact plantations as refugia, and determines the directional shifts (microsuccessions) in the insect fauna of urban plantings.

CONCLUSIONS

Trimming is an effective measure of the herbivore (aphid) control, but at the same time, if performed in June, it negatively affects all the preimaginal stages of the insectivore (ladybirds).

Early trimming (for instance, at the end of April) alleviates the negative action on insectivores.

In choosing whether to support a high abundance of insectivores or preserve the aesthetic appearance and "health" of plantations, advantage should be given to the latter.

Heterogeneity of agrotechnical "disruptions" in space and time determines the dynamics of plant colonization by actively migrating herbivores and insectivores.

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