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Complex of Amphibia Species in Ecosystems of a Big Industrial City[1]

V. L. Vershinin

Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences, ul. Vos'mogo Marta 202, Ekaterinburg, 620144 Russia

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Abstract – A population of Amphibia inhabiting urban territories was studied for more than 10 years (Amphibia, Anura, Ranidae: *Rana arvalis*, *R. temporaria*, *R. ridibunda*; Caudata, Salamandridae: *Triturus vulgaris*; Hynobiidae: *Salamandrella keyserlingii*). During the same period the pollution level of water bodies remained the same, but eutrophication increased. The abundance and the number of habitats decreased, the species ratio and species composition changed, the frequency of pathologies increased, the average fecundity decreased, the populational phenocharacteristics changed, and some adaptive features appeared that may be used in ecological monitoring.

It has been known for a while (Shvarts, 1976) that human activities on the planetary scale lead to significant changes in populations, but the microevolutionary consequences of the global activities of man remain in many ways unpredictable and often generally unknown. The present study is a generalization of the results of an investigation made over many years with reference to a species complex of Amphibia living under urbanized conditions combined with highly developed industrial production that has existed in the Urals for over 260 years. This makes it possible to estimate the level of changes that took place and also to reveal some general regularities of transformation and functioning of communities accompanying urbanization.

As Amphibia are consumers of several orders and a connective link in trophic chains of freshwater bodies and terrestrial ecosystems, they are the most convenient objects among terrestrial vertebrates for estimating anthropogenic changes in the environment. Abundance of larval aggregations of Amphibia allows for collection of a necessary quantity of material. A relatively high tolerance of Amphibia enables them to exist in places where other vertebrates are absent. During their entire life, Amphibia are attached to a comparatively small territory, contrary, e.g., to birds. The longer life span of Amphibia as compared with murine rodents makes it possible to observe the result of a prolonged action of anthropogenic factors on the organism.

MATERIAL AND METHODS

The data within the urban agglomeration of Ekaterinburg and adjacent territories were collected from 1977 to 1991. In collection and treatment of the material the standard zoological methods were used. During the course of study the cadaster of habitats of Amphibia on the urban territory was compiled, their species composition was studied, and the complex estimation of environmental conditions of habitats was elaborated and carried out. Hydrochemical analyses were made by the Bureau of Designs and Technology at the Ural Research Institute of Water Management (Ural'skii Nauchno-Issledovatel'skii Institut Vodnogo Khozyaistva).

The present article analyzes many years of material obtained for the same populations. Along with traits of the species composition, spatial populational structure, and phenotypic specificity, which can be obtained over a sufficiently short period, there are features revealed through prolonged systematic observations. The selection of criteria used in ecological monitoring is also based on complex long-term investigations.

RESULTS

Distribution of Amphibia on an urban territory is mosaic and irregular (see the figure). Small water bodies used by Amphibia for existence and reproduction are, in more than half of the cases, of technogenic origin. During the period of observations the frequency on the city territory suffered certain changes. Thus, while before the period 1984 - 1985 the species ranged in the following order as to their width of distribution (in decreasing order) – *Rana arvalis*, *R. temporaria*, *Triturus vulgaris*, *Salamandrella keyserlingii*, up to 1990 the sequences has changed – *Rana arvalis*, *R. ridibunda*, *Triturus vulgaris*, *Salamandrella keyserlingii* (due to degradation of newt habitats and distribution of *Rana ridibunda*). Of the 27 habitats of Amphibia within the city boundary and in suburbs that existed in the beginning of investigations, 11 have already been destroyed by economic activities, and in two of them Amphibia have disappeared. This is due to the fact that the

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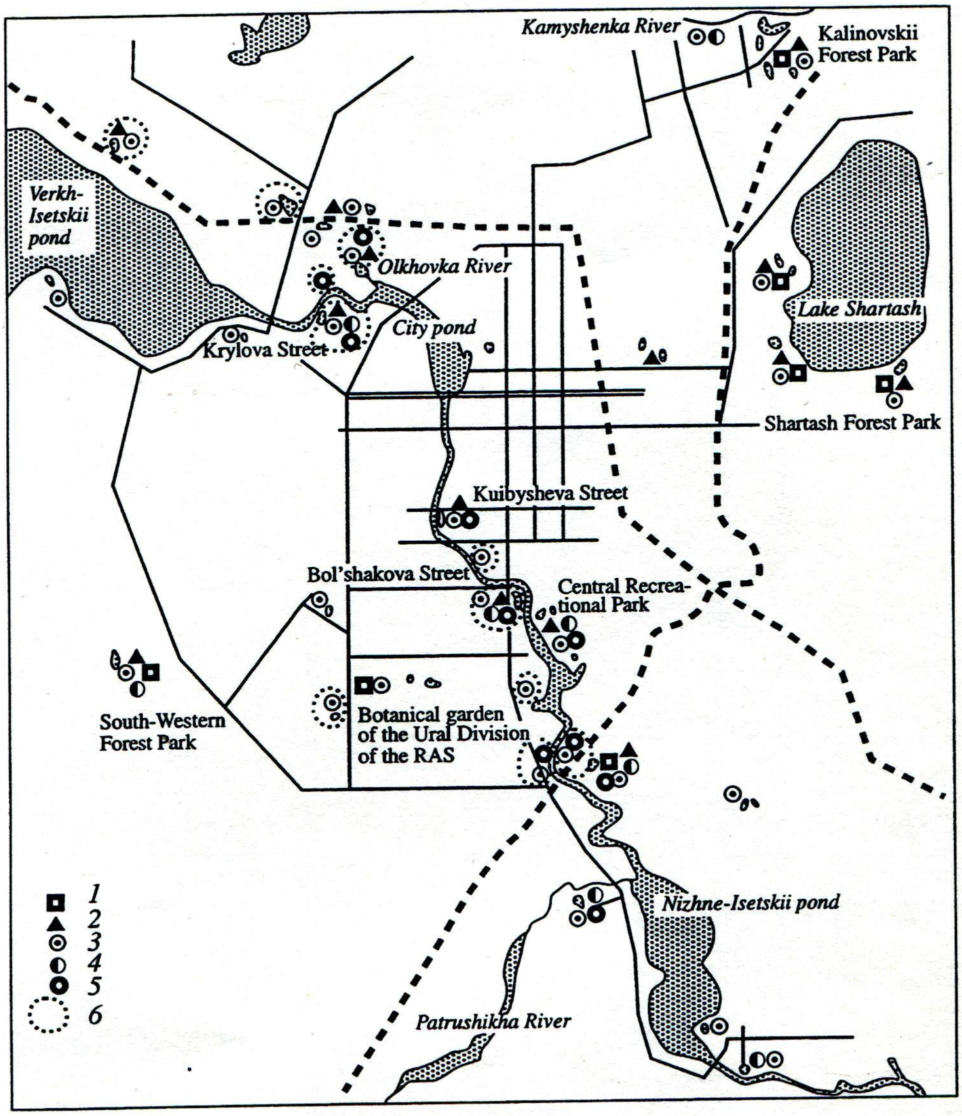

Distribution of Amphibia within the city of Ekaterinburg: *1 – Salamandrella keyserlingii*; *2 – Triturus vulgaris*, *3 – Rana arvalis*; *4 – R. temporaria*; *5 – R. ridibunda*; *6* – disappeared habitats.

construction of city objects is still carried out without consideration of the territorial fauna and without any ecological appraisal.

During the last decade no significant changes took place in the pollution level in urban and suburban territories (Table 1). Concentrations of sulfate and petroleum products in water bodies are, as before, higher by an order of magnitude than in water bodies in the country. In habitats in the zone of multistoried construction the level of synthetic surfactants is significant (Table 2) and lead concentrations, in most cases, exceed the maximum permissible concentrations. The content of oxygen-oxidizable organic matter increased (BOD_5 index) in all water bodies of the city, pointing to the increasing eutrophication (see Table 1).

The population density of aboriginal species populating the zone of multistoried construction generally decreased for 10 years (Table 3). In the zone of low-building construction the tendency for a reduction in the population density is the same (except one population of *Rana temporaria* and introduced *R. ridibunda*). The changes are not so uniform in populations in the forest park belt. Thus, the abundance of the dominant species *R. arvalis* increased (although in the Shartash forest park, in comparison with the level of 1977 – 250 individuals – it remained low). *Triturus vulgaris* and *Salamandrella keyserlingii* now occur more rarely in the degrading and most polluted Shartash forest park, while in the Kalininskii forest park the numbers of *Salamandrella keyserlingii* increased. In populations out of town significant changes are noted only in the population of *Rana arvalis* (the numbers increased more than 4.5 times).

The possibilities for reproducing various species of Amphibia on the urban territory significantly differ.

Table 1. Some hydrochemical parameters of water bodies, mg/l

Zone	1981			1989		
	sulfate	petroleum products	BOD_5	sulfate	petroleum products	BOD_5
Multistoried construction	94	3.3	6	95	2.3	9
Low-building construction	6	1.7	4	25	0.75	10
Forest park	36	0.98	4	20	0.5	7
Countryside	6.4	0.88	5	9.6	0.58	5

Table 2. Range of hydrochemical parameters of spawning water bodies

Zone	pH	Surfactants, mg/l	Pb concentration, mg/l	TDS, g/l
Multistoried construction	6.0 - 8.4	0.18 - 4.20	0.03 - 0.19	0.4198 - 0.8157
Low-building construction	6.0 - 8.3	0.12 - 0.62	0.02 - 0.08	0.3174 - 0.5668
Forest park	5.2 - 8.2	0.18 - 0.64	0.03 - 0.37	0.0714 - 0.4867
Countryside	5.8 - 8.2	0.08 - 0.4	0.03 - 0.06	0.1236 - 0.1584

Table 3. Change in the numbers of main Amphibia populations over 10 years

Zone	Habitat	1980					1990				
		1	2	3	4	5	1	2	3	4	5
Multistoried construction	Olkhovka River	0	360	62	0	0	0	0	24	0	5
	Krylova Street	0	138	10	14	100	0	36	8	9	10
	Belinskogo Street	0	n	14	4	15	0	30	26	8	28
Low-building construction	Samoletnaya Street	27	154	132	16	2	4	40	72	10	7
	Patrushikha River	0	0	13	206	0	0	0	40	604	6
Forest park	Shartash	433	95	83	0	0	136	28	136	0	0
	Kalinovskii	363	217	31	0	0	406	183	94	0	0
Countryside	Rezhevskii road (24th km)	163	35	176	0	0	144	50	826	0	0

Note: 1 – *Salamandrella keyserlingii*; 2 – *Triturus vulgaris*; 3 – *Rana arvalis*; 4 – *Rana temporaria*; 5 – *Rana ridibunda*; n – no data.

Salamandrella keyserlingii normally reproduces only in the forest park zone of the city, as it cannot withstand the transformation of plant communities and the related microclimatic modifications (Ishchenko, 1961; Bannikov *et al.*, 1969). *Triturus vulgaris* is less demanding in the composition of plant communities; it needs mainly a herbaceous shelter that supports the humidity of the superficial layer of air (Garanin, Popov, 1958). Newtreproduction is absent only in highly polluted water bodies in the city (Vershinin, 1983). Populations of *Rana temporaria* may rather successfully exist in the urban landscape (Lebedinskii, 1984) provided that nonfreezing and adequately aerated water bodies are available for wintering. The lower ecological plasticity and tolerance of this species should be noted in comparison with *Rana arvalis* (Vershinin, 1987a; Vershinin, Trubetskaya, 1992); this seems to be related to dominance of a hereditary component over an environmental component in ontogenesis (Surova, 1988). On the territory of Ekaterinburg the most successfully reproducing species is *Rana arvalis*, which also dominates in natural ecosystems of the Urals. A high polymorphism and a wide reaction norm contribute to its successful reproduction in technogenous landscapes as well.

The *Rana ridibunda* introduced in Ekaterinburg does not reproduce every year even under conditions of thermal pollution of water bodies, and not all isolated groups reproduce (Vershinin, 1990a). During the observation term the broods of the current year were recorded in 1980, 1981, and from 1988 through 1991. Within its geographical range this species is known to manifest exceptional stability in the face of pollution and anthropogenic transformation of the environment (Misyura, 1989). The maximum values of survival rate (immediately after metamorphosis) of species under different levels of anthropogenic impact are indicated in Table 4.

It is known that under conditions of pollution the process of egg formation itself may be disturbed. In the zone of industrial pollution in Amphibia the modification of

Table 4. The upper limit of survival during metamorphosis in urban populations of Amphibia, % of the number of laid eggs

Zone	*Salamandrella keyserlingii*	*Rana ridibunda*	*Rana arvalis*	*Rana temporaria*
Multistoried construction	No reproduction	57.7	5.0	2.5
Low-building construction	No reproduction	No reproduction	2.3	3.39
Forest park	18.1	No reproduction	3.39	n
Countryside population	0.5 (Tagirova, 1979)	No reproduction	0.66	n

Table 5. Frequency of the striata morph in populations of *Rana arvalis* and *R. ridibunda*

Zone	Adults			One-summer-old individuals		
	n striata	% striata	*n* total	*n* striata	% striata	*n* total
			Rana arvalis			
Multistoried construction	43	41.2	107	955	45.4	2104
Low-building construction	17	40.5	42	176	40.7	432
Forest park	48	35.6	135	961	27.0	3558
Countryside population	8	18.6	44	315	18.8	1672
			R. ridibunda			
Multistoried construction	120	99.2	119	331	36.2	914

protein and lipid metabolism is noted (Misyura, 1982), followed by deviations in the normal development of sexual products (Misyura, 1985). Moderate or insufficient nutrition causes a significant increase in the number of atretic ovocytes and reduction in the weight of ovaries (Saidapur, Prasadmuthv, 1988). A similar phenomenon is noted in fish under conditions of anthropogenic impact – mass resorption of eggs took place under strong deterioration of environmental conditions (Koshelev, 1988). Such changes in a group of spawners cause the appearance of egg masses with eggs without embryos and the decrease in fecundity of animals in populations exposed to increasing urbanization. Thus, the average number of eggs in an egg string of *Salamandrella keyserlingii* in a population of the Shartash forest park dropped to 58.7 ± 2.9 pcs from 105 ± 5.8; in some populations of *Rana arvalis* in the zone of multistoried construction a decrease in the average number of eggs in the egg mass to 833 - 925 pcs was noted (in a population in the country – 1167 - 1049 pcs). Chemical pollutants modify the protein composition of egg membranes and then prevent normal swelling and development of embryos (Hazelwood, 1970). The percentage of anomalous egg masses in populations of *Rana arvalis* inhabiting the urban territory of Ekaterinburg fluctuates in different years from 0.23 to 44.6% (of the total number of egg masses). In populations of *Rana temporaria* the occurrence of uncommon egg masses fluctuates from 0.7 to 12.5%; in *Salamandrella keyserlingii* – from 0.4 to 3.9% (Vershinin, 1990b).

The prolonged sustainable existence of populations of such species as *Rana arvalis* and *R. ridibunda* under urban conditions implies the presence of adaptive changes of different levels. Thus, investigation of neuromuscular excitability of adult *Rana arvalis* revealed an increase in the excitation threshold in frogs from the zone of multistoried construction (Vershinin, Tereshin, 1989) and an increase in the heart index in one-year-old frogs of the same population (Vershinin, 1985). We believe that this indicates physiological adaptation to the factor of higher disturbance. Investigation over many years of dynamics of the liver index of one-summer-old *Rana temporaria* has demonstrated the specificity of changes in this parameter in populations over the whole urban territory (Zones II, III, IV) and higher values of the index in the *Rana arvalis* population in the zone of multistoried construction (Vershinin, 1992), which seems to depend on the reaction of the organism to a high level of environmental pollution. Populations of newts in the zone of multistoried construction have demonstrated a behavioral adaptation – a longer period of submerged mode of life in adults.

A higher frequency of rarer phenotypes may serve as a criterion of a population's reaction to pressure of a new factor (Pavlov, 1982). For urban populations of *Rana arvalis* and *R. ridibunda*, a stable shift in the ratio of the frequency of the morph striata is noted in comparison with the populations in natural surroundings (Vershinin, 1987b, 1990). Frogs of this morph seem to possess selective advantages in populations of the zone of multistoried construction. In *Rana arvalis* some distinctions of metabolism are revealed (Dobrinskii, Malafeev, 1974) that can control the adaptive value of striata under conditions of pollution and urbanization. Among one-summer-old *Rana ridibunda* of this morph, some animals have a significantly thinner medial strip (0.3 - 0.5 vs. 1.0 - 2.0 mm), the frequency of this morph being 4.5%. Table 5 represents a sum

Table 6. Average body length of Amphibia

Species	Zone	
Salamandrella keyserlingii	Low-building construction	Countryside population
Males	61.6 ± 0.9 (*n* = 4)	57.6 ± 0.9 (*n* = 19)
Females	57.8 ± 3.9 (*n* = 2)	57.8 ± 3.9 (*n* = 21)
Triturus vulgaris	Multistoried construction	Countryside population
Males	37.2 ± 0.34 (*n* = 57)	36.4 ± 1.7 (*n* = 5)
Females	39.8 ± 0.29 (*n* = 99)	36.9 ± 0.87 (*n* = 13)
One-summer-old	20.9 ± 0.66 (*n* = 43)	17.8 ± 1.4 (*n* = 7)
Rana ridibunda	Multistoried construction	Countryside population
Males	83.1 ± 1.8 (*n* = 6)	See Note
Females	76.5 ± 10.4 (*n* = 7)	
One-summer-old	26.7 ± 0.1 (*n* = 122)	
Rana arvalis	Multistoried construction	Countryside population
Males	55.0 ± 1.3 (*n* = 33)	52.2 ± 1.2 (*n* = 27)
Females	46.2 ± 1.6 (*n* = 32)	53.3 ± 1.6 (*n* = 12)
One-summer-old	18.5 ± 0.48 (*n* = 65)	14.5 ± 0.16 (*n* = 90)
Rana temporaria	Multistoried construction	Low-building construction
Males	70.8 ± 2.3 (*n* = 22)	64.8 ± 0.95 (*n* = 57)
Females	63.2 ± 4.1 (*n* = 4)	57.9 ± 2.3 (*n* = 30)
One-summer-old	16.0 ± 0.22 (*n* = 44)	15.1 ± 0.55 (*n* = 39)

Note: According to published data the body length of one-summer-old *Rana ridibunda* in natural populations ranges from 18 to 23 mm (Iskakova, 1954), and the body length of adults ranges from 60 to 110 mm (Toporkova, 1978) versus 50 - 115.5 mm in the city by our data.

frequency of the striped morph in populations of *Rana arvalis* and *Rana ridibunda* exposed to different impact levels. The change in the frequency of phenotypes at increasing urbanization also is characteristic of other *Rana* species (Lebedisnkii, 1984; Zhukova *et al.*, 1986).

Another feature of the urban populations of Amphibia is their larger body size (Table 6), probably related to a better surface–volume ratio in larger specimens under conditions of pollution (lower area per unit weight). This feature is recorded in males and one-summer-old *Rana arvalis*, in adult *Salamandrella keyserlingii* and *Rana temporaria*, and in adult and one-summer-old *Triturus vulgaris* and *Rana ridibunda*. Rapidly growing larvae earlier attain the size at which they become less vulnerable to pollution and predators (Werner, 1986). The large body size in Amphibia under conditions of anthropogenic impact was also noted by other authors (Buganeva, 1983; Gogoleva, 1985; Ivanova, 1982; Misyura, 1989; Ushakov *et al.*, 1982).

One of the negative sides of the reaction of populations to anthropogenic factors (mainly to changes in the chemistry of the environment) is the increase in frequency of morphological anomalies caused by genetic changes, developmental deviations, anomalous regeneration, neoplasms, etc. The occurrence of anomalies differs in Urodela and in Anura and also in one-summer-old and adult animals. In Urodela the anomalies are more frequent in adults than in one-summer-old animals. These are mainly the cases of anomalous regeneration, developmental pathology, and neoplasms, which are explained by sensitivity of the Urodela to chemical pollution and the persistence of their capacity for regeneration for their whole life.

Small areas of territories of isolated groups and low numbers of animals in aggregations of anurans entail a considerable increase in the probability of mating of closely related animals, which yields some genetic defects, some of them being expressed externally. Various morphological anomalies are recorded practically in all populations of Amphibia, depending on the biological specificity of this group of vertebrates, but the frequency of anomalies of all kinds also depends on the extent of anthropogenic impact (Table 7). This should be related to a complex of causes, including changes in the chemistry of the environment, spatial delimitation of aggregations, and low numbers of the nucleus of spawners.

DISCUSSION

Thus, the investigation of distribution of Amphibia on an urban area and of some populational features during a prolonged period has demonstrated that under these conditions the evolutionarily young species have an advantage, are widely distributed within the city (and often dominate in the natural ecosystems), and

Table 7. Frequency of morphological anomalies in Amphibia, % (in parentheses – the number of individuals)

Zone	Adults	One-summer-old individuals
Salamandrella keyserlingii		
Low-building construction	16.7 (6)	No reproduction
Forest park	3.9 (386)	1.3 (300)
Countryside population	12.5 (40)	0 (5)
Triturus vulgaris		
Multistoried construction	8.3 (156)	2.3 (43)
Low-building construction	4.48 (67)	6.25 (17)
Forest park	1.7 (60)	0 (56)
Countryside population	5.3 (19)	0 (7)
Rana ridibunda		
Multistoried construction	1.68 (119)	2.0 (914)
R. arvalis		
Multistoried construction	10.3 (107)	3.95 (3168)
Low building construction	4.8 (42)	1.94 (877)
Forest park	3.0 (135)	1.8 (4885)
Countryside population	2.2 (44)	0.88 (2382)
R. temporaria		
Multistoried construction	0 (26)	2.4 (250)
Low-building construction	0.87 (345)	0.54 (1667)

successfully reproduce. On the contrary, successful reproduction of Urodela was not observed in habitats with the maximum anthropogenic impact (*Salamandrella keyserlingii* normally propagates only in the forest park zone). Variation of the main morphological features in less resistant *Salamandrella keyserlingii* and *Rana temporaria* decreases with the increase in urbanization. In the more resistant *Rana arvalis* in the forest park zone and the zone of low-building construction the variation increases, sometimes surpassing the values for the population in the country (Vershinin, 1987a).

An unbiased assessment of the environmental state based only on determining concentrations of toxic compounds in the air, water, and soil is not possible, since it is necessary to know the ways and mechanisms by which particular pollutants act on ecosystems. A final conclusion may be made only on the basis of long-term observations. We have elaborated some recommendations on the use of Amphibia in ecological monitoring (Vershinin, 1990c). With reference to the used typification, we conventionally call the level of transformation in the forest park zone the initial level, in the zone of low-building construction – the average level, and in the zones of multistoried construction – a considerable level. The initial levels of transformation of ecosystems may be estimated by changes in the species composition of Amphibia, the numbers of background species, density, the decrease in fecundity, the increase in the asymmetry of egg masses, and accumulation of pollution.

At an average level of changes due to increasing pollution and a radical change in the plant component of communities *Salamandrella keyserlingii* disappears; negative trends begin to noticeably prevail in populations of Amphibia. This level of transformation and pollution of ecosystems can be well estimated by greater frequency of all types of morphological anomalies and of mutation background, by the appearance of anomalous egg masses of *Rana temporaria*, and by the presence of physiological adaptations. The Amphibia living in the most transformed habitats are characterized by some adaptive features of the populational rank. A considerable level of modification of ecosystems is determined by specific dynamics of the numbers of larvae and one-summer-old individuals of *Rana temporaria*, significant changes in the genetic structure of populations (negative and adaptive), peculiarities of the phenocharacteristics, and formation of populations of those species that are introduced and are capable of existence only in the anthropogenically transformed environment. Changes are observed also in trophic interrelations of one-summer-old individuals of *Rana temporaria*. Thus, in the food range the amount of plant eaters increases noticeably from the 53rd stage to the 54th stage, contributing to greater metabolism rate and indicative of shorter trophic chains.

Most Amphibia populations within the city boundaries are permanently endangered by direct or indirect destruction, as the economic activities are still carried out without consideration of the local fauna. Therefore, the isolates populated by Amphibia need protection.

In conservation of Amphibia the habitats and breeding sites should be protected, i.e., spawning water bodies and adjacent plant communities. Water bodies should be protected from pollution and garbage litter. The height of the grass layer of vegetation, which serves as a shelter and feeding ground, is also of great importance. At the early stages of development many egg masses of Amphibia desiccate on shallow grounds, and to decrease the embryonic mortality it is possible to transfer egg masses to deeper places. During construction near the habitats of Amphibia the water bodies and adjacent territories should be protected from pollution and destruction. It is advisable to create parks in such places, and when the parks are created the available water bodies on their territory should not be destroyed. Conservation of elements of the natural landscape is a positive point, as otherwise the shelters and wintering sites of Amphibia would suffer.

It should also be noted that removal of garbage from water bodies during the period when one-summer-old amphibians emerge on dryland may cause their destruction. Garbage removal should be made at other times. Draining and road construction in immediate proximity to breeding sites and habitats render negative effects on the numbers of Amphibia. Digging of various trenches near habitats of Amphibia entails trapping of numerous amphibians during the period of reproduction, migration for wintering, and at other times (e.g., in only one of the urban forest parks, in one month over 12000 amphibians fell into a trench for a cable and poles).

Undoubtedly, the protection and investigation of small "ecological units" that exist on urban territories and supply the habitats for Amphibia are necessary, since this permits monitoring of the urban ecosystems to be performed and also meets man's quest to create an ecologically harmonious urban environment.

Among specific features of cytological, physiological, and phenotypic levels of the investigated populations and species complexes, both adaptive and negative components at all stages of the life cycle are elucidated that control, on the one hand, the potential possibility of an increase in reproduction and tolerance of populations and, on the other hand, the low buffer properties of the formed structures. The formed system possesses a special configuration of flows of matter and energy that is determined by a complex relationship of the dynamics of numbers, population structure, and the metabolic level.

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