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PREFACE

Urban ecology is a rapidly developing scientific area, which undergoes constant change as new knowledge on the subject is acquired. Although modern cities are considered areas with low biodiversity the effects of urbanization on species richness can be either positive or negative, depending on several variables. Some of these variables include: taxonomic group, spatial scale of analysis, and intensity of urbanization.

Several studies show that each city is unique with its characteristics and environment, thus presenting new and interesting opportunities for species inhabiting them and new possibilities for scientists to study them. Having in mind that there are quite extensive urban ecology studies (including on amphibians and reptiles) on most western European cities, the cities from Eastern Europe and their biodiversity are somewhat overlooked and not quite well studied yet. The current monograph presents the data on the ecology of amphibians and reptiles from a 10-year study period and is the first of its kind for the city of Plovdiv (South Bulgaria) and one of the few for Eastern Europe.

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CHAPTER ONE

INTRODUCTION

In contemporary environmental research, the study of the impact of urbanization on animal and plant communities, the preservation of biodiversity in cities, and the creation of a sustainable urban environment for the biota and its proper management is taking a very serious place.

The concentration of the human population in cities and the significant urban development and growth rates have led to the emergence of specific, particular environmental conditions, forming populations and communities of animals and plants, that are significantly different from those occurring in nature. The emergence of modern cities is also associated with the emergence of urban ecosystems. The species' composition, structure of populations and communities in these ecosystems is by default not accidental, but is a reflection of objective processes occurring in specific conditions in the urbanized territories (Vershinin 1997, 1-47).

Urbanization is recognized to be one of the main factors for habitat loss leading to local biodiversity extinction in urban areas (McKinney 2008, 161-176). It was also recognized that the negative impact of habitat loss can be ameliorated through adequate management plans. Furthermore, habitat loss and habitat configuration are two of the most important aspects when studying ecosystems in urban areas (Löfvenhaft, Runborg, and Sjögren-Gulve 2004, 403-427).

As urbanization is spreading rapidly across the globe, a basic challenge for conservation is to understand how it affects biodiversity. Although urbanization often causes extinctions of native species, the complex nature of urban land use can have a complicated influence on local biodiversity. Several studies have described the effects of urbanization on species richness, indicating that urbanization can affect species richness either positively or negatively, depending on several variables. Some of these variables include: taxonomic group, spatial scale of analysis, and intensity of urbanization (McKinney 2008, 161-176). Under the conditions of urbanization, some species undergo a process of synanthropization, while other species cannot adapt to the new conditions and are isolated in separate fragmented populations, or pushed outside the city (Vershinin 1997, 1-47).

According to Marzluff (2001, 19-47), recent reviews of birds (the most studied group on this issue) indicate that species richness generally decreases with increasing urbanization in most cases or does not change significantly. A lot less attention is given to the other vertebrate taxa, especially aquatic and semi-aquatic species (fishes, amphibians and reptiles).

Amphibians and reptiles represent a very important component of urban ecosystems. They occur in a variety of terrestrial and aquatic habitats and therefore tolerate the impact of human activity to varying degrees. This leads to a reduction in their diversity compared to natural conditions and changes in the structure of their populations and communities. Scientific publications of recent years have shown opportunities for the use of amphibians and reptiles as model animal groups in complex urban studies (Vershinin 1997, 1-47; Bolshakov, Pyastolova, and Vershinin 2001, 315-325; Ficetola and DeBernardi 2004, 219-230; Jellinek, Driscoll, and Kirkpatrick 2004, 294-304). However, this problem is still poorly studied in Europe, and especially in Bulgaria.

The problem of clarification of the synanthropic processes and changes occurring in the amphibian and reptile populations in urban environments is very topical, and studies in this area will help to effectively plan conservation and restoration activities for the urban herpetofauna.

The city of Plovdiv is the second largest city in Bulgaria and its territory covers mainly the urbanized environment and adjacent terrains. The favorable geographic location of the city, the presence of the Plovdiv hills and the influence of the Maritsa River determine the existence of unique natural areas with rich biodiversity. Amphibians and reptiles, as important components of this biodiversity, have not been the subjects of extensive research so far. This raises the need to carry out the fullest possible study of the processes of synanthropy and the adaptation of populations and communities of amphibians and reptiles to the environmental factors in the city of Plovdiv and its surroundings.

CHAPTER TWO

MAIN PRINCIPLES OF URBAN ECOLOGY

According to Klausnitzer (1990, 1-246), urban ecology studies living organisms in relation to their environment in cities and other human settlements. It is an independent, specific area in ecology and, more specifically, in landscape ecology (Dedyu 1989, 1-408). Objects of the study of urban ecology include human settlements, industrial zones, roads, etc. One of its main objectives is the optimization of the urban environment from an ecological point of view. Its main tasks can be summarized in the following two points: (1) organization of environmental monitoring in cities and their surroundings; and (2) study of the state of flora and fauna, pollution due to pesticides and heavy metals, and the impact of urban factors on living organisms, including on human health (Dedyu 1989, 1-408).

Urbanization poses the following problems to humanity: the vulnerability of fragile urban ecosystems; concentration and migration of the human population from villages to cities; poor quality of the habitats of many animal species; loss of biodiversity and fertile land; accumulation of pollutants, changing the local climate, etc. (Stearns 1970, 1006-1007; McDonnell and Pickett 1990, 1232-1237; Trepl 1994, 15-19; Sukopp and Zerbe 1996, 107-124; Cornelis and Hermy 2004, 385-401).

Historically, the big city is an unsustainable end-stage in the development of human settlements (Klausnitzer 1990, 1-246). In the current monograph, the European concept of "city", a "socio-spatial unit with a cohesive residential and administrative centre", is used, unlike the American one, which defines it as "a conglomerate of settlements in whose center are administrative buildings, and the residential buildings are in the surrounding area" (Skibniewska 1994, 11-14).

The urban environment is a heterogeneous mosaic of residential and industrial buildings, road networks, parks and other types of green areas (McIntyre 2000, 825-835). The detailed mapping and classification of the built-up area among the open spaces, or the so-called "urban matrix", is used to monitor and model the processes taking place in urban ecosystems, in architectural plans and in management plans (Pauleit and Duhme 2000, 1-20). The other main components of land cover in cities are green areas, urban parks, open spaces, etc. Their spatial characteristics are related to the study, maintenance and conservation of biodiversity in cities (Cornelis and Hermy 2004, 385-401).

According to McDonnell and Pickett (1990, 1232-1237), in order to properly understand and manage the urbanization processes, it is necessary to classify the individual components of the urban environment (physical and chemical factors, populations, communities, ecosystems and human intervention) and assess the links between them to identify ecologically important impacts of urban factors.

According to Bunce and Jongman (1993, 3-10), the main concepts in landscape ecology, which are the theoretical basis in urban ecology as well, are the following:

1. *Sustainability concept.* Sustainability is the capacity of an ecosystem to maintain life and preserve it as a system. This is one of the main approaches in landscape ecology, in which it is essential to maintain ecosystems that self-reproduce and do not lose nutrients or species/genes. This principle is increasingly included in urban planning programs.

2. *Landscapes hierarchy concept.* Landscapes operate at different levels, and include complexes of different elements. Research design may include territories from hundreds of thousands of square kilometers to individual fragments of several square kilometers (for example, in cities).

3. *Urban-to-rural gradient concept.* This was proposed for the first time in the 1970s by Klausnitzer, on the basis of his research in Leipzig (1990, 1-246). Consequently, the concept was further elaborated by McDonnell and Picket (1990, 1232-1237) and McDonnell et al. (1997, 21-36). According to the main postulate of the concept, urbanization causes changes in the natural environment that can be traced to different levels of organization of the biota, from the city center (urban area) through their suburban zone to the natural (often semi-natural) habitats in the rural area. These environmental variables affect the structure and function of populations, communities or entire ecosystems (McDonnell and Pickett 1990, 1232-1237).

4. *Concept of biodiversity conservation.* The greater the anthropogenic pressure on semi-natural biotopes, the greater the need to take care of the biodiversity. This concept is key to planning and managing landscapes. Human interference can disturb or maintain high biodiversity, depending on the mode of action. Many natural and semi-natural ecosystems, which in the past occupied enormous territories, are now fragmented as part of the urban green areas (Sukopp and Weiler 1988, 39-58).

5. *Concept of the metapopulation.* This concept represents the relationships between subpopulations in more or less isolated fragments in one landscape and helps us understand the impact of progressive isolation (e.g. in cities) on the vegetation of these fragments and associated animal populations. Typical processes in metapopulations are temporary extinction and recolonization. There are three key points:

a) Subpopulation dynamics (rate of disappearance and immigration) – if a fragment is small and isolated, the rate of disappearance may exceed that of recolonization and the subpopulation will disappear.

b) The connectivity between the fragments – important landscape variables include the absence of barriers and the presence of corridors.

c) The spatial and temporal variation (gradient) of the quality of the biotope – this is influenced by the absence or presence of human activity.

Another theoretical basis of urban ecology as part of the landscape ecology comes from *The Theory of Island Biogeography* (MacArthur and Wilson 1967). In the context of habitat fragmentation, this theory addresses individual urban habitats as *"islands"* that belonged in the past to a large natural biotope. These "islands" are small in size, isolated from each other by barriers (roads or buildings), with changed microclimatic conditions (Klausnitzer 1990, 1-246). Preston (1962, 185-215) predicts that the big non-fragmented habitat would support many of the rare species that do not exist in the small, isolated "islands" of the same habitat, and therefore it should have a richer species composition. MacArthur and Wilson (1967) themselves emphasize that the widespread use of the theory is limited because the processes of dissemination, competition, invasion and adaptation are some of the most difficult to study and interpret.

The issue of the impact of habitat isolation and fragmentation on biodiversity has been studied by many authors (Bunce and Jongman 1993, 3-10; Clergeau 1996, 102-104; Fisher 1998, 155-158; Kotze and Samways 1999, 1339-1363; Bolger et al. 2000, 1230-1248; Gibbs 2000, 314-317; Gibb and Hochuli 2002, 91-100; Hunter 2002, 159-166; Wade et al. 2003; Cornelis and Hermy 2004, 385-401; Schoereder et al. 2004, 1-8; Zanette, Martins, and Ribeiro 2005, 105-121), using spiders, carabid beetles, ticks, flies, butterflies, bees, birds, squirrels, etc. as model species.

CHAPTER THREE

ECOLOGICAL STUDIES ON MODEL GROUPS OF ANIMALS IN URBAN ENVIRONMENT

More and more studies are beginning to address ecological characteristics of urban areas around the world (Sukopp and Werner 1982; McDonnell and Pickett 1990, 1232-1237; Sukopp and Numata, 1995; Grimm et al. 2000, 571-584). Human activity can directly affect land cover, which in turn determines biodiversity, primary productivity, soil quality and water regime. Urban areas also influence the microclimate and air quality, changing the characteristics of the ground surface, which leads to the production of additional heat – the so-called *"urban heat island effect"* (Oke 1987, 1-24). The increase in impervious surfaces in cities is reflected in both geomorphological and hydrological processes in changes in water runoff and deposition of sediments (Leopold, 1968; Arnold and Gibbons, 1996). Transformation of land cover favors organisms capable of rapid colonization that can quickly adapt to these new conditions and tolerate the presence of people, and in urban environments they usually dominate over many endemic and sensitive organisms with a narrower ecological specialization. As a result, urbanized areas typically have unusual combinations of community-forming organisms in which *"ecotone species"* typically increase and *"interior species"* decrease (Marzluff 2001, 19-47).

According to some authors (Trojan 1981, 3-12; Niemelä et al. 2000, 3-9; Collins et al. 2000), the low anthropogenic press increases the species richness of some animals in the cities. This is due to the newly created urban habitats, their mosaic location and the many ecotones that urbanization creates (Frankie and Ehler 1978, 367-387). However, with a high degree of degradation of the environment, one or two species remain dominant, while others disappear or occur in very few habitats and play no significant role in the flow of energy into the ecosystem (Trojan, Górska, and Wegner 1982, 125-135).

There are relatively few generalized and in-depth studies on animals in urban areas, except for their consideration as pests (McIntyre 2000, 825-835). Little attention is paid to the influence of the developing urban environment on their abundance and diversity. There is still no way to know how most animals respond (positively, negatively or neutrally) to urban conditions.

There are three main types of reactions of animal communities to urban environment changes: degradation, enrichment and transformation (Trojan, Górska, and Wegner 1982, 125-135). Reactions may be direct (deaths due to pollution or habitat loss) or indirect (as a result of habitat change or abundance of food resources) (McIntyre 2000, 825-835).

Birds are perhaps the most obvious and easily recognizable fauna in cities and as such have received considerable attention from ecologists compared to other animal groups. Individual local communities can be characterized either with low species richness and high abundance or with high species richness and low abundance (Wood, Greenwood and Agnew 2003, 206-216). Increasing the abundance of some species of birds in urban environments is due to their ability to absorb extraneous resources that are abundant in cities (for example, food and nesting sites) and habitats that occur only in man-made areas (Jones and Wieneke 2000, 53-60).

Local ecological factors influencing urban habitats also play an important role in determining the presence and distribution of species in urban environments (White et al. 2005, 123-135). Most studies in this regard show that preserving the high diversity of birds in habitats is directly dependent on the creation and maintenance of structurally complex and floristically diverse habitats that are dominated by native species (Recher and Serventy 1991, 90-102; Parsons, French, and Major 2003, 43-56; French, Major, and Hely 2005, 545-559; White et al. 2005, 123-135). Sewell and Catterall (1998, 41-64) add that maintaining indigenous plant species and not exotic ones is key to the successful recovery and maintenance of insectivorous birds in cities.

According to many authors, native mammalian species, especially those of medium size, are most sensitive to habitat changes due to urbanization with accompanying secondary influences, such as introduced predators, inter-species competition and human-induced mortality (How and Dell 1993, 28-47; Tait, Daniels, and Hill 2005, 346-359). Currently, most of the studies on mammalian urban communities focus on different aspects of the food spectrum and species' behavior (Markus and Hall 2004, 345-355), with significantly fewer studies focusing on the study of species-habitat interactions at different levels of the dynamic urban environment. The most commonly studied species of mammals are those that are easily recognized and observed (Smith and Murray 2003, 291-301; Goldingay and Sharpe 2004, 663-677; Matthews et al. 2004, 159-168).

Similar to bird studies, achieving a more comprehensive understanding of the interactions between mammalian communities and urban habitats is a significant challenge. The reason for this is the large diversity of habitats and factors that act at different ecological levels in cities, affect the distribution and species abundance, and cause species-specific reactions. How and Dell (2000, 198-217), for example, suggest that mammals are generally more influenced by habitat fragmentation, whereas McAlpine et al. (2005, 7-11) conclude that the loss of habitats plays a more important role than their fragmentation and the density of the road network.

In the scientific literature, amphibians and reptiles are united by many authors under the common name "*herpetofauna*", although the two classes of animals exhibit different reactions to urbanization and related environmental changes. There is currently a huge gap in our knowledge of the understanding of habitats' requirements for both reptiles and amphibians in urban environments. For example, it is known that some species of reptiles are well adapted to urban environments, while others are limited to fragmented parts of habitats and often disappear locally. However, this pattern varies greatly between cities (How and Dell 1994, 132-140; 2000, 198-217; Cooper 1995, 21-28). Similar to birds and mammals, there is no information on the importance of the various environmental factors that affect different levels of the amphibian and reptile communities. It seems that the significance of the different factors varies between reptiles and amphibians, both as groups and between species (How and Dell 2000, 198-217; Anderson and Burgin 2002, 630-637; Jellinek, Driscoll, and Kirkpatrick 2004, 294-304). For example, according to Jellinek, Driscoll, and Kirkpatrick (2004, 294-304), lizards are more influenced by the composition and structure of vegetation, not by the size of habitats (with some exceptions). Drinnan (2005, 339-349) shows that the size of the habitats has a significant impact on amphibians. White and Burgin (2004, 109-123), on the other hand, argue that frogs are mainly affected by changes in water runoff and water quality. Drinnan (2005, 339-349) further reports that there is a threshold for amphibians and reptiles, and species more sensitive to urbanization require a significantly large fragmentation of habitats to ensure their survival (> 50 ha), while more adaptive species can inhabit much smaller fragments (approximately 4 ha).

Since invertebrates play a significant role in the ecosystems' functionality, such as reductants, parasites, pollinators and prey for many other species (Bhullar and Majer 2000, 171-173), it is crucial to understand the impact of urbanization on their populations and communities as well. A summary of current research on the problem shows that the large fragments of habitats with natural vegetation (Gibb and Hochuli 2002, 91-100; Clark 2004, 78-81; Hochuli et al. 2004, 63-69), the diversity of vegetation (Emery and Emery 2004, 124-130; Burwell and Grimbacher 2005, 62-76) and the quality of the habitats (Gibb and Hochuli 2002, 91-100; New and Sands 2002, 207-215; Dover and Rowlingson 2005, 599-609) are critical factors for the protection of invertebrates in cities. Other factors important for particular species include: the regime of fires (Gibb and Hochuli 2002, 91-100; New and Sands 2002, 207-215; Dover and Rowlingson 2005, 599-609) and inter-species relationships (Hochuli et al. 2004, 63-69; Burwell and Grimbacher 2005, 62-76; Dover and Rowlingson 2005, 599-609). Unlike other animal groups, the impact of urbanization on invertebrates is extremely specific and depends on the study group.

So far, studies have been carried out in Bulgaria on certain groups of the fauna of Sofia (Nankinov 1982, 387; Milchev 1985, 195-203; Markova 1998, 44-50; Markova, Georgieva, and Karadjova 2000, 19-24; Markova and Alexiev 2001, 151-157; Kamburova 2004, 451-455; Stoyanov, Kyutchukov, and Domuschiev 2004, 437-450; Antonova and Penev 2008, 103-110; Penev et al. 2008, 483-509). There are some in-depth systematic studies on terrestrial snails (Dedov and Penev 2000, 121-131; 2004, 307-318), carabid fauna (Niemelä et al. 2002, 387-401; Stoyanov 2004, 401-415), spiders (Antov et al. 2004, 355-362) and nematode fauna (Mladenov, Lazarova, and Peneva 2004, 281-297), conducted on the basis of the urban gradient concept. Episodic studies have been made on the species diversity of other invertebrate groups: ants (Antonova 2004, 423-428; Lapeva-Gjonova and Atanasova 2004, 417-422); centipedes (Stoev 2004, 299-306); opiliones (Mitov and Stoyanov 2004, 319-354); aphids (Tasheva-Terzieva 2004, 365-370), flies of the Phoridae family (Langourov 2004, 429-436) and others.

The majority of the above-mentioned articles on the vegetation and fauna of Sofia, as well as those about the climate and the soils of the city, are included in the book *Ecology of the City of Sofia. Species and Communities in an Urban Environment*, edited by Penev et al. (2004).

The landscape and architectural aspects of Sofia's ecology are discussed in the monograph of Kovachev (2005, 1-368), which also analyzes the historical development of the green areas of Sofia City from the end of the 19th century until the end of the 20th century.

A study on the terrestrial snails of Stara Zagora City and some rural areas was carried out by Irikov and Georgiev (2002, 5-16) and Georgiev (2008, 147-151). The authors examined the habitat distribution of snails in urban environments with some ecological and zoogeographic notes.

Studies on vertebrate animals in the urban environment have been conducted mainly in the city of Sofia on birds (Nankinov 1981, 25-35; 1982, 387; Kiuchukov and Todorov 1995, 7-9; Kodzhabashev, Dyankov and Simova 2000, 303-320; Kiuchukov 1995, 169-174; 2000a, 84-96; 2000b, 81-89; Kamburova 2004, 452-455) and mammals (Markov et al. 1994, 100-105). The bats of Plovdiv City and Stara Zagora City have also been studied (Stoycheva, Georgiev, and Velcheva 2008, 538-542; 2009, 83-93; Tilova et al. 2008, 129-136).

CHAPTER FOUR

A SYNOPSIS OF THE ECOLOGICAL STUDIES ON AMPHIBIANS AND REPTILES IN THE URBAN ENVIRONMENT

Studies on amphibians and reptiles in the urban environment

The majority of studies on amphibians and reptiles conducted in urban environments are mainly confined to the inventory of species composition and the distribution of species in the studied territory (Vershinin 1990, 67-71; Ruchin et al. 2003, 225; Chibilev 2003, 70-73; Kral, Pellantova, and Kokes 1983, 51-66; West and Skelly 1997, 197-203; Anton 1999, 211-232; Leontyeva and Semenov 1999, 69-275; Padhye and Mahabaleshwarkar 2000; Thakur and Gour-Broome 2000; Toth 2002, 163-167; Foster 2004; Rugiero 2004, 151-155; Strugariu et al. 2007, 31-43). Another major part of the research is focused on the habitat distribution of amphibians and reptiles in urban environments (Ruchin et al. 2003, 225; Beebee 1979, 241-257; Banks and Laverick 1986, 44-50; Chovanec 1994, 43-54; Webb and Shine 2000, 93-99; Fearn et al. 2001, 573-579; Shine and Koenig 2001, 271-283; Ensabella et al. 2003, 396-400; Gomez-Zlatar 2003, 1-105; Kühnel and Krone 2003, 299-315; Ficetola and DeBernardi 2004, 219-230; Bosman and Munckhof 2006, 23-25; Gagne and Fahrig 2007, 205-215; Garden et al. 2007, 669-685; Nicoară and Nicoară 2007, 22-29; Ottburg, Pouwels, and Slim 2007).

Studies on the influence of habitat loss, fragmentation and isolation on amphibians and reptiles

The importance of habitat loss and fragmentation, resulting in the reduction of amphibian and reptile populations, has been outlined in recent years by Cushman (2006, 231-240) and Gardner, Barlow, and Peres (2007, 166-179). These authors identify a gradient of increasing anthropogenic pressure on amphibian species, with a reduction in the structural complexity of the habitats. Many amphibian populations are naturally fragmented in the urban landscape at the local level, which can be included in larger networks of metapopulations at a regional level (Marsh and Trenham 2001, 40-49; Smith and Green 2005, 110-128). In addition, amphibians require additional habitats in different spatial scales to successfully complete their complex life cycle, and for this reason, their populations are fragmented or structured as metapopulations (Pope, Fahrig, and Merriam 2000, 2498-2508; Marsh and Trenham 2001, 40-49). Urbanization reduces the ability of these subpopulation networks to function due to the construction of roads and urban infrastructures, such as buildings, fences and open areas that suppress and hamper the distribution of amphibians (Vos and Chardon 1998, 44-56).

Almost all studies report a negative correlation between the level of urbanization and amphibian species' composition, presence/absence, abundance or community structure (Bunnell and Zampella 1999, 614-627; Atauri and de Lucio 2001, 147-159; Houlahan and Findlay 2003, 1078-1094; Willson and Dorcas 2003, 763-771; Woodford and Meyer 2003, 277-284; Pearl et al. 2005, 76-88; Rubbo and Kiesecker 2005, 504-511; Bowles, Sanders, and Hansen 2006, 111-120; Parris 2006, 757-764; Gagné and Fahrig 2007, 205-215; Skidds et al. 2007, 439-450). In general, the decline of amphibian and reptile populations in urban areas is directly related to changes in the landscape structure due to urbanization, which leads to a reduction in wetlands and greater isolation (Lehtinen, Galatowitsch, and Tester 1999, 1-12; Rubbo and Kiesecker 2005, 504-511; Parris 2006, 757-764; Gagné and Fahrig 2007, 205-215).

Surveys on changes in amphibian and reptile habitats over a longer period of time show feedback between urbanization and existing habitats. Gibbs (2000, 314-317) conducted an urban-rural gradient mosaic analysis in the city of New York, USA, and reported a decrease in the number of wetlands and an increase in distances to the nearest adjacent habitat, correlating with the change in settlement patterns and rural development to urban. According to Wood et al. (2003, 206-216), the reduction of the populations of the northern crested newt (*Triturus cristatus*) in the UK is due to the loss of temporary standing water bodies caused by urban development. According to the same authors, these critical habitats are more endangered in the UK, as they are usually shallow, vulnerable to soil drainage and highly sensitive to pollution. In the same way, spring basins, which are the habitat of many amphibian species in the northeast of the United States, are also at risk of destruction from urbanization due to their small size and short-wave periods (Grant 2005, 480-487) and due to the fact that they are rarely placed under any protection (Dodd and Smith 2003, 94-112; Semlitsch 2003, 8-23). Small, temporary wetlands (<4.0 ha) are of great importance for the reproduction of amphibians and play a critical role in reducing distances between isolated habitats (Gibbs 2000, 314-317).

Urban habitats' creation and restoration

Amphibians and reptiles with common habitat requirements may exist within urban landscapes as they are able to use artificial habitats such as garden lakes, decorative fountains, micro dams, and irrigation canals. Indeed, there is evidence that some species have benefited from the construction of water reservoirs and wetlands, especially during the initial urbanization phase when amphibian colonization is less obstructed, as they can replace the functions of rural or natural ponds destroyed during this process with artificial ones (Hammer and McDonnel 2008, 2432-2449). For example, the common frog (*Rana temporaria*) in the UK occurs in cities and suburban areas more than in rural areas, most likely due to the abundance of artificial water basins (Carrier and Beebee 2003, 395-399). However, water basins and wetlands in urban and suburban areas are often limited in their suitability for amphibian species with more specific habitat requirements. In many of the ponds, there are artificially maintained exotic species of fish or inadequate hydrological regimes; they are often contaminated (fertilizers, sediments, pesticides, grease and oil, heavy metals), or are often visited by humans and have artificial lighting that makes reproduction difficult (Knutson et al. 1999, 1437-1446; Rubbo and Kiesecker 2005, 504-511; Baker and Richardson 2006, 1528-1532).

In addition, the characteristics of urban basins may exclude the occurrence of certain species in them. For example, a vertical wall of the pool may mean that it is only suitable for tree frogs (*Hyla arborea*), as they are able to climb out when leaving the pool (Parris 2006, 757-764). Urban wetlands are also often surrounded by roads and infrastructure that can form barriers to the distribution of amphibians, potentially making them inaccessible for moderate to widespread species (Rubbo and Kieseker 2005, 504-511). Therefore, some species with more specific habitat requirements can be attracted to artificially created habitats, but they cannot support a population, and so artificial urban habitats can function as *"ecological traps"* or *"source-sink" systems* (Battin 2004, 1482-1491). Some recreational activities could turn some, otherwise inappropriate, urban ponds and wetlands into amphibian breeding grounds. For example, wetlands in the Minnesota City area, USA, have been successfully restored by removing parts of the dikes, allowing the pools to be replenished and then colonized by amphibians (Lehtinen, Galatowitsch, and Tester 1999, 1-12). The restoration of wetlands on an island on the Danube River in Austria has been successful in attracting several amphibians by creating places where no carnivorous species are present (Chovanec 1994, 43-54).

In order to restore wetlands in urban landscapes to provide suitable habitats for amphibians, it is necessary to create and maintain appropriate fluctuations in the water regime, the presence of adjacent land habitats, good water quality, a connection with surrounding populations and a lack of local and exotic species of predatory fish (Beebee 1979, 241-257; Petranka et al. 2007, 371-380).

Quality of the amphibian and reptile habitats in the cities

The quality of the amphibian habitats is influenced by the size and type of vegetation in the ponds, wetlands and surrounding terrestrial habitats; the water regime, the quality of water, the presence of predators and competitors, and the nature and frequency of human-induced disturbances. Suitable habitats for amphibians should provide opportunities for breeding, foraging and dispersal, as well as places for refuge and hibernation (Wells 2007). Poor habitats cannot support viable populations, and such scarce habitats could potentially turn into “source-sink” systems and thus reduce the size of a larger metapopulation (McKinney 2002, 883-890).

Vegetation. Urbanization can lead to the loss of aquatic vegetation in lakes, swamps and streams, or the loss of forest and other terrestrial plant communities from the landscape. Aquatic vegetation provides shelter for larvae and adult amphibians and some reptiles, as well as places for laying eggs (Skidds et al. 2007, 439-450). Furthermore, vegetation in wetlands as well as terrestrial plant communities provide opportunities for dispersion, food, shelters and places for hibernation (deMaynadier and Hunter 1999, 441-450).

Water regime. The water regime and length of the ponds have a strong influence on the structure and composition of amphibian communities and aquatic reptiles (Werner et al. 2007, 1697-1712). For example, some species require short-lived ponds that retain water for a short period of time (e.g. one or two months), while others need permanent water habitats that never dry up. Rubbo and Kiesecker (2005, 504-511) suggest that the water regime can play a significant role in the distribution of amphibians in the urban-to-rural gradient due to the complexity of the life cycle of the species and the inter-specific relationships (predatory fish and other predators). The water regime can be changed as a result of urbanization, including changes in the degree, duration, frequency and peak of the water level, and the amount of water flowing. For example, urban development in the Portland area of Oregon, USA, has led to the transformation of large, shallow, well-overgrown, short-lived wetlands into smaller, deeper wetlands with less vegetation and more stable, permanent wetlands that are often inhabited by fish (Kentula, Gwin, and Pierson 2004, 734-743). The loss of temporary wetlands in this area has reduced the habitats of several amphibian species whose larvae have a rapid growth rate (e.g. *Ambystoma macrodactylum*), but on the other hand increasing the life of the water basins has allowed the existence of species with larvae with a longer period of metamorphosis (e.g. *Rana catesbeiana*) and some reptiles (Pearl et al. 2005, 76-88).

Urban water management can change the water regime of urban wetlands by increasing the probability of the drainage of water basins, especially during dry seasons or by re-directing the water elsewhere (Hogan and Walbridge 2007, 1142-1155). This practice may lead to a lower reproductive success of amphibians in urban and suburban areas. Larvae or metamorphosed specimens can perish under these conditions if they are unable to move to another wetland or wet micro-habitat. Changes in the hydrological regime can lead to the loss of refugia and breeding sites, reduced abundance of food, etc. (Willson and Dorcas 2003, 763-771). Increasing urbanization in riparian areas has the potential to reduce the quality of habitats of amphibians and aquatic reptiles and lead to a reduction of their populations. For example, Price et al. (2006, 436-441) suggest that the increased urbanization level from 1972 to 2000 near Davidson in North Carolina, USA, may be the cause of a significant and rapid reduction in the salamander population reported in this region.

Studies on the terrestrial habitats of amphibians and reptiles

Terrestrial habitats are particularly important for reptiles. Many amphibians also require terrestrial habitats that are not used for breeding but for access to essential resources such as shelter and food as well as hibernation sites. For this reason, the availability of suitable terrestrial habitats can be an important element of the mosaic of habitats suitable for amphibians and reptiles in the cities (Semlitsch 2003, 8-23). For example, Baldwin, Calhoun, and deMaynadier (2006, 442-453) report that the *Rana sylvatica* chooses wooded wetlands because it uses forests as a shelter in the summer after breeding. The migration of this species ranges from 120 to 340 m. For this reason, the conservation of amphibian populations in urban and suburban landscapes requires the conservation of not only aquatic habitats but also the terrestrial habitats near them.

The quality of terrestrial habitats also determines whether amphibians and reptiles can successfully disperse and move between green areas through the urban matrix. The movement and survival of amphibians and reptiles in terrestrial habitats is a critical moment that ensures successful distribution and recolonization within regional metapopulations (Semlitsch 2003, 8-23), but maintaining the connectivity between terrestrial habitats is a major challenge in urban and suburban landscapes (Gibbs 2000, 314-317). The dense network of roads, buildings, fences and other physical barriers does not allow many of the amphibians and reptiles to successfully spread among the numerous habitats (Knutson et al. 1999, 1437-1446; Dodd and Smith 2003, 94-112). Amphibians and reptiles are often killed while crossing roads, and such road traffic mortality may have significant impacts on their populations in cities, especially near breeding sites (Carr and Fahrig 2001, 1071-1078; Eigenbrod, Hecnar, and Fahrig 2008, 35-46). For example, using survival tables for *Ambystoma maculatum*, Gibbs and Shriver (2005, 281-289) show that per year the risk of adult mortality is about 10% and may lead to the destruction of the local population. The same authors have calculated that 22-73% of the population in central and western Massachusetts, USA, will be exposed to this threshold level of risk.

Predators and competitors

The presence of predatory fish, especially non-native species, in ponds and wetlands often leads to a reduction in the abundance and species diversity of amphibians. The larvae of many amphibian species are vulnerable to predation by some species of fish (Kats and Ferrer 2003, 99-110). Predatory fish are often absent from water basins and wetlands with a short water regime, and they are prone to remain in more durable ponds that often dominate urban and suburban areas (Kentula, Gwin, and Pierson 2004, 734-743). For example, Rubbo and Kiesecker (2005, 504-511) reported that fish are more common in permanent wetlands in cities and suburban areas than in less permanent ponds in rural areas in central Pennsylvania, USA. Therefore, they find that urban water basins have a lower abundance of amphibian larvae than those in rural areas.

In addition to the negative effects of predatory fish and some birds, amphibians are also subjected to negative pressures from pet animals, especially cats and dogs. For example, Wood et al. (2003, 206-216) estimated that the domestic cat population in the UK amounted to approximately 9 million specimens, killing 4 to 6 million reptiles and amphibians over a five-month study period.

Introduced non-native species of amphibians and reptiles, on the other hand, may compete with native species due to limited resources in urban areas (Kiesecker 2003, 113-126).

Studies on direct anthropogenic pressure

It is well known that amphibians react to direct human disturbances, artificial light (Baker and Richardson 2006, 1528-1532) and noise pollution (Bee and Swanson 2007, 1765-1776), as a result of which their reproductive behavior may change, potentially reducing the success of reproduction and thus disturbing the dynamics of the population. For example, Baker and Richardson (2006, 1528-1532) show that males of *Rana clamitans melanota* make less reproductive calls and move more often when exposed to artificial light than in normal light conditions.

In addition, many urban wetlands are intensively visited by people as they are used for active recreation. Rodriguez-Prieto and Fernandez-Juricic (2005, 1-9) assess the impact of the flow of people on *Rana iberica* in central Spain. By simulating different levels of human presence near the water basins used by frogs, they found about an 80% and 100% reduction in the basins used by frogs in correlation with a 5-fold and 12-fold increase in direct human disturbances, respectively.

In urban and suburban areas, amphibians are also collected by humans for food, as bait for fishing or as pets, which can also lead to a reduction in population size or to the introduction of invasive species in urban areas (Jensen and Camp 2003, 199-213).

Ecological studies on amphibians and reptiles in Bulgaria

Studies on the ecology of amphibians and reptiles in Bulgaria began in the 1960s. The first ecological publication in the Bulgarian herpetological literature belongs to Tuleshkov (1959, 169-180) and it is dedicated to the habitat selection of the sand viper (*Vipera ammodytes*). Subsequently, a number of studies have been carried out on the ecology of various representatives of amphibians and reptiles in Bulgaria. Peters (1963, 203-222) published some data on the ecology of *Lacerta trilineata* – mostly habitat preferences, 24-hour activity and the diet of the species in the country.

In 1963, Beshkov and Tsonchev conducted the first large study on the population, habitat preferences, daily and annual activity, feeding and breeding of the fire salamander (*Salamandra salamandra*) of the Vitosha Mts. (Beshkov and Tsonchev 1963, 79-91).

In the 1970s, Vladimir Beshkov conducted the first large-scale ecological and biological study of the Greek stream frog (*Rana graeca*), giving, for the first time, data on its diet, breeding, daily and seasonal activity, as well as the home range, habitat preferences and some population characteristics of this species (Beshkov 1970a, 79-91; 1970b, 159-180; 1972, 25-136).

The same author has explored different aspects of the ecology and biology of amphibians and reptiles in Bulgaria, giving, for the first time, data on: the breeding of *Zamenis longissimus* and *Vipera ammodytes* (Beshkov 1975, 75-83; 1977, 3-11); the population density and home range of *Bombina variegata* (Beshkov and Jameson 1980, 365-370); the reproduction and migration of *Rana temporaria* (Beshkov and Angelova 1981, 34-42; Beshkov 1988, 34-39); the population size, reproduction and migrations of *Bufo bufo* (Beshkov, Delcheva and Dobrev 1986, 62-70); the population size of *Mauremys rivulata* (Beshkov 1987, 58-64); the seasonal and daily activity of *Vipera ammodytes* (Beshkov 1993a, 3-12); and the reproduction of *Zootoca vivipara* (Beshkov, Guillaume and Heulin 1994).

In 1984, the largest and one-of-a-kind study on the distribution, population size and conservation measures of both tortoise species in Bulgaria – *Testudo hermanni* and *Testudo graeca* – was published (Beshkov 1984, 14-34).

The only study on the impact of industrial pollution on the distribution of amphibians and reptiles in Bulgaria from that period also belongs to the same author (Beshkov 1978, 3-11).

Several more targeted studies have been carried out over the past few years on the ecology of certain species of reptiles in terms of specific environmental problems – the effect of fires on the population dynamics and structure of the green lizard (*Lacerta viridis*) (Popgeorgiev and Mollov 2005, 95-108), *Testudo hermanni* and *Testudo graeca* (Popgeorgiev 2008a, 115-127) and other amphibian and reptile species (Popgeorgiev 2008b; 2009) in the Eastern Rhodopes Mts. and Sakar Mts.; on the population size and habitat preferences of six species of sympathetically occurring lizards (Tzankov 2005, 235-242) and one study on the population size and density, sex and age structure of *Testudo hermanni* and *Testudo graeca* (Ivanchev 2007, 153-163; Zhivkov et al., 2007, 1015-1022; Zhivkov, Raikova-Petrova and Trichkova 2009, 11-26).

In the last few years, a series of studies have been carried out on the possibility of using some morpho-physiological parameters of *Pelophylax ridibundus* for the purposes of ecological bio-monitoring in Bulgaria (Boyadzhieva et al. 2001, 165-171; Zhelev et al. 2001, 99-104; Zhelev, Adzhaliyski and Koycheva 2002a, 121-128; 2002b, 113-120; Zhelev and Mollov 2004, 137-151; Zhelev, Petkov and Adzalijski 2005, 229-236; Zhelev, Angelov and Mollov 2006, 235-244; Velcheva et al. 2006, 155-160; Zhelev 2007, 181-190 and others).

Literary overview on the species composition of amphibians and reptiles in the city of Plovdiv and its surroundings

An extensive review of the literature on the herpetofauna in the territory of the city of Plovdiv and its surroundings showed that there is data on 10 species of amphibians and 16 species of reptiles (not in alphabetical order):

Triturus ivanbureshi (Arntzen and Wielstra, 2013) – Kovachev (1912, 1-90); Buresh and Tsonkov (1941, 71-237); Angelov and Kalchev (1961, 18-21);

Lissotriton vulgaris (Linnaeus, 1758) – Kovachev (1905a, 1-50; 1905b, 1-13; 1912, 1-90); Buresh and Tsonkov (1941, 71-237); Angelov (1960a, 7-40); Angelov and Kalchev (1961, 18-21);

Bombina bombina (Linnaeus, 1761) – Kovachev (1912, 1-90); Buresh and Tsonkov (1942, 8-165); Angelov and Kalchev (1961, 18-21); Beshkov (1961, 16-18); Beškov and Beron (1964, 1-39); Beshkov et al. (1967, 5-10);

Bombina variegata (Linnaeus, 1758) – Angelov (1960b, 333-337); Angelov and Kalchev (1961, 18-21); Donev (1984b, 115-120);

Bufo bufo (Linnaeus, 1758) – Kovachev (1912, 1-90); Buresh and Tsonkov (1942, 8-165); Angelov (1960b, 333-337); Angelov and Kalchev (1961, 18-21);

Bufotes viridis complex – Buresh and Tsonkov (1942, 8-165); Angelov (1960a, 7-40; 1960b, 333-337); Angelov and Kalchev (1961, 18-21); Cyren (1941, 36-146); Euzet, Combes, and Batchvarov (1974, 129-140);

Pelobates syriacus balcanicus (Karaman, 1928) – Buresh and Tsonkov (1942, 8-165); Angelov and Kalchev (1961, 18-21); Beškov and Beron (1964, 1-39);

Rana dalmatina (Bonaparte, 1840) – Angelov (1960b, 333-337); Angelov and Kalchev (1961, 18-21); Popov (1973, 121-125); Bachvarov (1980, 183-190);

Pelophylax ridibundus (Pallas, 1771) – Angelov (1960a, 7-40; 1960b, 333-337); Popov (1973, 397-404; 1975, 13-17); Donev (1984a, 35-44; 1986, 81-102); Cyren (1941, 36-146); Bachvarov (1968, 143-152);

Hyla arborea complex – Angelov (1960a, 7-40; 1960b, 333-337); Angelov and Kalchev (1961, 18-21); Cyren (1941, 36-146);

Mediodactylus kotschyi (Steindachner, 1870) – Shkorpil (1897, 1-23); Kovachev (1905b, 1-13; 1910, 1-16; 1912, 1-90); Buresh and Tsonkov (1933, 150-207); Müller (1939, 1-17);

Ablepharus kitaibellii (Bibron et Bory, 1833) – Mollov (2005b, 79-94);

Emys orbicularis (Linnaeus, 1758) – Kovachev (1910, 1-16); Buresh and Tsonkov (1933, 150-207); Angelov (1960a, 7-40); Kirin (2001, 95-98);

Testudo graeca (Linnaeus, 1758) – Buresh and Tsonkov (1933, 150-207); Drenski (1955, 109-166); Angelov (1960a, 7-40); Beshkov et al. (1967, 5-10);

Testudo hermanni (Gmelin, 1789) – Shkorpil (1897, 1-23); Drenski (1955, 109-166);

Lacerta trilineata (Bedriaga, 1886) – Kovachev (1907, 217-218; 1912, 1-90); Buresh and Tsonkov (1933, 150-207); Angelov, Tomov and Gruev (1966, 99-105);

Lacerta viridis (Laurenti, 1768) – Buresh and Tsonkov (1933, 150-207); Angelov (1960a, 7-40); Angelov, Tomov and Gruev (1966, 99-105); Donev (1984c, 45-50);

Podarcis muralis (Laurenti, 1768) – Kovachev (1905b, 1-13); Buresh and Tsonkov (1933, 150-207);

Podarcis tauricus (Pallas, 1814) – Kovachev (1912, 1-90); Buresh and Tsonkov (1933, 150-207); Angelov, Tomov and Gruev (1966, 99-105); Donev (1984c, 45-50); Cyren (1933, 219-246);

Dolichophis caspius (Gmelin, 1789) – Buresh and Tsonkov (1934, 106-188);

Coronella austriaca (Laurenti, 1768) – Kovachev (1905b, 1-13; 1912, 1-90); Buresh and Tsonkov (1934, 106-188);

Zamenis longissimus (Laurenti, 1768) – Kovachev (1912, 1-90); Buresh and Tsonkov (1934, 106-188); Beshkov and Dushkov (1981, 43-50);

Elaphe sauromates (Pallas, 1814) – Kovachev (1912, 1-90); Buresh and Tsonkov (1934, 106-188);

Natrix natrix (Linnaeus, 1758) – Kovachev (1912, 1-90); Buresh and Tsonkov (1934, 106-188); Angelov (1960a, 7-40); Bachvarov (1969, 191-196) Kirin (1994a, 35-39; Kirin; 1994b, 41-46; 1995, 77-80);

Natrix tessellata (Laurenti, 1768) – Kovachev (1912, 1-90); Buresh and Tsonkov (1934, 106-188); Angelov (1960a, 7-40); Kirin (1994a, 35-39);

Vipera ammodytes (Linnaeus, 1758) – Kovachev (1905b, 1-13; 1912, 1-90); Buresh and Tsonkov (1934, 106-188); Beshkov and Dushkov (1981, 43-50).

Ecological studies on amphibians and reptiles

Apart from the fragmentary data on the distribution of individual amphibians and reptiles, which are also found in Plovdiv City, two preliminary studies on amphibians and reptiles have been conducted in Plovdiv and its surroundings. One studies the problem of the impact of road traffic on the populations of two species of amphibians (*Bufotes viridis* complex and *Bufo bufo*) in Plovdiv (Mollov 2005a, 82-88). The other study is an overview article on the species composition and distribution of amphibians and reptiles in three protected areas in Plovdiv with ecological, conservation and zoogeographic notes (Mollov 2005b, 79-94).

Currently, there is a huge gap in the data on the abundance, density, sex and age structure of the populations, habitat distribution, seasonal and daily activity, and other ecological characteristics of amphibian and reptile populations and communities in the city.

CHAPTER FIVE

METHODOLOGY FOR URBAN ECOLOGICAL STUDIES ON AMPHIBIANS AND REPTILES

The data presented in this monograph was obtained in the period from March 2007 to October 2010 in the territory of Plovdiv City and its surroundings (see Chapter Six). For some of the species, data from older observations (2002-2006) from the same region was also used.

Field methods. The amphibians and reptiles were determined visually, using available field guides (Bannikov et al. 1977, 1-414; Arnold and Ovenden 2002, 1-288; Biserkov et al. 2007, 1-196). For every recorded species, a valid Bulgarian and Latin name is given following Biserkov et al. (2007, 1-196) and Speybroeck, Beukema and Crochet (2010, 1-27). A new specific name for the eastern taxon of the *Triturus karelinii* group was proposed by Wielstra et al. (2013, 441-453) – *Triturus ivanbureshi* (Wielstra and Arntzen, 2013). The species *Hyla orientalis* (Bedriaga, 1890), mentioned for Bulgaria by Frost (2013), seems to have a contact zone with *Hyla arborea* in Bulgaria, as they co-occur in close proximity in eastern Serbia and northeastern Greece (Stock et al. 2012, 1-9). According to Tzankov and Popgeorgiev (2015, 131-139), both taxa were recorded via bioacoustics in the country, so it is listed as "*Hyla arborea* complex" in the current work. Finally, the generic name *Bufotes* (Rafinesque, 1815) has been assigned to green toads, and even though the species *Bufotes viridis* (Laurenti, 1768) was listed for Bulgaria, it appears that *Bufotes variables* are also present in the country. Since the taxonomic state of the green toad in Plovdiv City is still unclear, it is also listed as "complex".

In some cases, amphibians and reptiles were captured manually or with the help of snares, loops, etc. for more accurate determination before being released at the same place. Some individuals were identified by their sounds, eggs, larvae or skin sheds.

For each recorded species, the following general and specific information was collected: