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Green infrastructure of a city and its biodiversity: take Warsaw as an example

Abraham A. MABELIS

Alterra, Wageningen UR, postbox 47, 6700 AA Wageningen, The Netherlands; e-mail: bram.mabelis@wur.nl

Abstract: Many cities are expanding rather fast. As a result several green areas vanished, while the remaining ones are getting more and more under urban pressure. Changes in the size and configuration of green urban areas will affect the liveability of a city for citizens, as well as the local survival probability of many plant and animal species. In order to keep the city liveable and healthy not only water, energy and waste flows should be managed properly, but also green urban areas. Area, connectivity and quality of habitat patches are crucial for the survival of many species. Therefore, biotope types should be maintained in a proper setting of a network, which makes the exchange of individuals of species with a poor dispersal capacity possible. For getting public support for the maintenance of nature quality of green areas a good communication between responsible authorities and citizens is conditional. Monitoring of nature quality is necessary in order to keep biodiversity at a high level. A monitoring programme can be part of an Ecological Policy Plan of the city.

Key words: urban ecology, urban biodiversity, urban green, ecological network

INTRODUCTION

During the last decades the built-up area of Warsaw expanded very fast. As a result several green areas vanished, while the remaining ones are getting more and more under urban pressure. Consequently, more green areas will disappear in future. This will affect the liveability of the city. Green areas are important for improving the urban climate: trees and bushes increase air humidity, give some cooling on hot days, produce oxygen and filter the air. Moreover, urban green retains rainwater and its soil has important cleaning properties: some noxious substances can be broken down, at least if the soil is not too much polluted. Urban green has not only an ecological function, but is also important for recreation. For both functions it is important to keep biodiversity at a high level.

The Convention on Biological Diversity (Rio de Janeiro 1992), which was signed by many countries, aims at the maintenance of ecosystems, species and genetic diversity. This Treaty also has consequences for local communities, according to Local Agenda 21. The city council can meet its obligations by establishing a sustainable green infrastructure. The maintenance of such a robust green infrastructure is not only important for the survival of native plants and animal species, but also for maintaining a healthy environment and for giving citizens the opportunity to relax and experience nature. In order to prevent alienation of citizens from nature the presence of native species should be favoured above introduced exotic species, although the aim to maintain a high level of biodiversity in a city emanates mainly from the wish to keep it liveable and healthy (Kelcey 1978, Trojan 1981a, Goode 1989).

Ecological qualities of urban nature should be guaranteed despite urban processes. Therefore, a strategy should be followed in which water, energy and waste flows are managed properly (Tjallingii 1993, 1995, 1996). Moreover, fragmentation of urban green should be prevented as much as possible. Generally, urban green is less fragmented in the outskirts of the city than in the centre, where green areas are generally smaller and more isolated by roads and buildings.

For evaluating environmental quality the presence and absence of species which can disperse very well, but are sensitive to pollution, may be useful. For example the distribution of some Lichen species, gives an indication of differences in air quality. Similarly, water quality can be measured by changes in the presence of fish species and dragon flies, which are sensitive to water pollution.

For evaluating the spatial quality of urban nature, the distribution of common species, which possess a poor dispersal capacity, gives an indication of the isolation of suitable habitat patches of these species. Fragmentation of urban green by roads, houses, parking places, etc. will affect the exchange of individuals between local populations and hence the survival probability of many species in the city.

Before discussing the relation between the green infrastructure of a city and its biodiversity, some characteristics of the urban environment will be discussed.

URBAN ENVIRONMENT

In flat land a city like Warsaw rises up as a **rock island**. Buildings with holes, crevices and hiding places can be suitable for rock-dwelling birds and bats to hide, reproduce or hibernate, while old walls (with calcium-rich cement between the stones) can be suitable as habitat for wall plants. Moreover, cellars, which are constant cool and moist, add a kind of cave environment to the city. Several species use cellars to hibernate, like some beetles and night butterflies.

A city can also be considered as a **heat island**: the average temperature is higher in a city than in its surroundings, despite the fact that the sun will shine here less often and less fierce than in the countryside, due to air pollution. However, a great deal of the city surface is covered by buildings, asphalt and flat stones, which can preserve heat for a long time. The relative high temperature of the city is suitable for thermophilic species. Consequently, the northern limit of the distribution area of several thermophilic species is situated in cities. Examples are known of plants (Sukopp & Wurzel 1995), digger wasps (Whiteley 1994), longhorned beetles (Burakowski & Nowakowski 1981b), rove beetles and glow worms (Klausnitzer 1989) and springtails (Sterzyńska 1982), among others. Thanks to the warmer city climate birds can produce more clutches of eggs per year (Klausnitzer 1989). Moreover, winters are less severe in cities. Consequently water will freeze less easily, which may be profitable for water birds. On the other hand, the warmer climate of a city is disadvantageous for some insect species: e.g. a parasite can miss the connection with its host species (Garbarczyk 1982).

A city can also be considered as a **dry island**. Its stony environment causes that the air of a city is dryer than in its surroundings (Blume 1993). Generally the soil is also dryer in a city, despite the fact that it rains more often (Kuttler 1993). It appears that the proportion of hygrophilic species of several groups of insects will be lower inside a city than in its surroundings (Bańkowska 1981a, Pisarski & Kulesza 1982, Chudzicka & Skibińska 1994). A shift from hygrophilic species to dry-tolerant species from the outskirts of a city to the centre is ascertained in Warsaw for several groups of animals: worms (Kasprzak 1986), spiders (Klausnitzer 1987), harvest-spiders (Czechowski et al. 1981), springtails (Sterzyńska 1982, 1987), carabid beetles (Czechowski 1981a, 1982), lady beetles (Czechowska & Bielawski 1981), flies (Górska 1981), scorpion flies (Czechowska 1982), ants (Pisarski & Czechowski 1978, Pisarski 1982b) and parasitic wasps (Garbarczyk 1982). However, it appears that dry-tolerant species with a narrow ecological amplitude occur less often in the city of Warsaw (Pisarski & Kulesza 1982).

Soil and water in a city is enriched with **nutrients** from garbage and dung. Garbage from vegetable or animal origin is easy attainable in a city and attracts many animal species (Spirn 1984). It explains the great proportion of animals here which live on organic garbage (Trojan et al. 1982, Bańkowska et al. 1985). The combination of a relative warm microclimate and the availability of an abundance of food makes a city attractive for many insect species (Frankie & Ehler 1978). A lot of them are most common in urban environments and are therefore known as synanthropic species. The number of species which live from organic substances (detritus) decreases to the centre of the city, e.g. mites (Niedbała et al. 1982). Part of these detritus-eating species, which can live up in green areas in the centre occur here in great densities. These species are synanthropic and have a wide distributional range (Jędryczkowski 1981). Several carrion-beetles and carrion-eating flesh flies (*Calliphoridae*) belong to this category (Klausnitzer 1989, Trojan et al. 1982, respectively). Species which larvae live from dung, like dung flies, profit from the presence of dogs. Especially the dung fly *Scataphaga stercoraria* L. can be very common locally (Draber-Mońko 1981a). The proportion of synanthropic species of many animal groups increases from the outskirts of Warsaw to the centre, as found in dung flies, midges, sow bugs, millipedes and spiders (Górska 1981, Wegner 1982, Jędryczkowski 1981, 1982; Krzyżanowska et al. 1981, respectively).

The high density of some mammal and bird species in the city is also explained by the availability of plenty of **food** (Luniak 1980, 1981, 1983; Sukopp 1990). Especially garbage- and seed-eaters can find sufficient food. In inner Warsaw rock-pigeon (*Columba livia* Gmelin) and house sparrow (*Passer domesticus* L.) accounted for 73% of the total breeding bird population (Nowicki 2001). A city gives shelter to relatively more granivorous birds and omnivorous birds, like the magpie (*Pica pica* L.), jackdaw (*Corvus monedula* L.), rook (*Corvus frugilegus* L.) and starling (*Sturnus vulgaris* L.), than to insectivorous and carnivorous birds (Tomialojc & Profus 1977). Some species, like the pigeon, have adapted their menu to city life and changed from seed-eaters to omnivorous birds (Klausnitzer 1989). A few birds of prey, like the peregrone falcon (*Falco peregrinus* Tunstall.) and kestrel (*Falco tinnunculus* L.), take advantage of this situation and catch more birds in the city than in its surroundings (Klausnitzer 1989).

Organic garbage and dung increases the nutrient content of the soil. Consequently, certain plant species of nutrient-rich soils will dominate at the cost of species of nutrient-poor soils. The result of this process is that insects which are dependent of plants from nutrient-poor vegetations will decrease in number and may eventually disappear.

Enrichment of waters with nitrogen and phosphorous may also have an impoverishing effect on flora and fauna. It stimulates the growth of blue-green algae (*Cyanophyta*), which by decomposition may cause oxygen deficiency with devastating effects for water life (Douglas 1983).

In general air **pollution** increases towards the centre of a city (e.g. for Warsaw: see Wyrwicka 1995). This becomes evident by considering the distribution of Lichen species which are sensitive to SO_2 (van Dam et al. 1986, Sukopp & Werner 1983). Air pollution has also a negative effect on the vitality of trees. Decreasing vitality of trees may lead to an increase of plant sucking insects, like cicadas (Chudzicka et al.1979, Chudzicka 1986ab) and aphids (Pisarski & Czechowski 1978). In contrast, leaf-eating insects, like caterpillars, beetles and sawflies, occur generally in low densities in the centre of a city (Pisarski & Trojan 1976, Chudzicka & Skibińska 1994). The effects of acid deposition on the soil fauna will be strongest in sandy areas with a low content of organic material. Increasing acidification of the soil may result in a strong decrease of earthworms and certain soil-arthropods, like springtails and click beetles (Sterzyńska 1987, Nowakowski 1986). The quality of the soil can also be influenced by trampling. Intensive trampling causes soil condensation, which affect adversely the number of micro-arthropod species (Garay & Nataf 1982).

In general **disturbance** of green areas increases also nearer to the centre of a city. Consequently, species which are sensitive to this factor will decrease in numbers and may in the end disappear from disturbed areas e.g. soil and bush breeding birds may disappear from green areas which are visited intensively and birds which can sing only softly will disappear from green areas near noisy roads (Luniak 1981, 1983). However, it seems that traffic noise is not a nuisance for most bird species: the composition of the breeding population did not change significantly over a distance of 1–400 m from a busy road in Warsaw (Luniak 1981).

A city is also a **light island**. Illumination can disturb animals, which are active at night: it can hamper their foraging (e.g. owls) and their orientation (e.g. night butterflies and migrating amphibians). Disorientation may increase the risk to become a road victim. Consequently, local populations of sensitive species may eventually disappear (de Molenaar et al. 1997).

The urban environmental factors, mentioned above, can explain the decrease in number of species of animals and plants from the outskirts of a city to the centre, as is apparent from inventories which are carried out in several cities, like in Warsaw (Pisarski 1982a, among others). However, the decrease of number of species to the centre can also be explained by the smaller size and more isolated position of habitat patches of many species, due to the increasing density of buildings and roads. The question arises in what respect urban biodiversity will be affected by these factors.

URBAN BIODIVERSITY

Urban biodiversity can be kept on a high level by maintaining different biotope types (ecosystems) and species. The maintenance of biodiversity should *not* be aimed at maximizing the number of species, because many exotic species are introduced by man, intentionally or accidentally. In general green urban areas, like parks and gardens, differ from their potential natural vegetation (Table 1). Amply half of higher plant species which occur in the centre of a city are introduced by man (Jackowiak 1994). Part of these species, which established recently can only live up to a couple of years in this new environment. No efforts are required to keep them. The same can be said of weedy invaders.

Table 1. Loss of native plant species with increasing urbanization in Poland (adapted from Kowarik 1990).

Type of settlement	% native species
Villages (near forest)	70–80
Small towns	60–65
Medium towns	50–60
Cities	30–50

Urban fauna is also strongly influenced by man, not only by transporting parasites, fleas, lice and mites with help of house animals, but also by importing products and accompanied invertebrate species. Many of these species occurred originally in (sub) tropical areas, but are nowadays distributed over the whole world. In a moderate climate zone they can only survive the winter by using heated residences, storehouses and glasshouses, like the eastern cockroach (*Blatta orientalis* L.), the pharao ant (*Monomorium pharaonis* L.) and the house cricket (*Acheta* domestica L.). The aspiration to maintain a high level of biodiversity in the city does not refer to such introduced species, but to the maintenance of characteristic urban species, which established without the help of man.

The number of characteristic species, which occur in a city, will be greater the more biotope types are present. The same applies to a more restricted area, like a park. The larger the park the easier it is to maintain different biotopes: e.g. woodland, shrub, grassland, marshland and water. Not only more stenotopic species, which are bound to a specific biotope, can profit from biotope variability, but also species which need a combination of biotopes for their living and reproduction, e.g. woodland for hibernating and water for reproduction (amphibians), woodland for nesting and grassland for foraging, e.g. song thrush (*Turdus philomelos* L.) and starling (*Sturnus vulgaris* L.). Variation of composition and structure of the vegetation within a specific biotope contributes also to species diversity, e.g. some species, which can be found in deciduous forests cannot be found in coniferous forests, and vice versa and some species which can be found in dense woodland cannot be found in open woodland, and vice versa. In general only part of a biotope is suitable as habitat for a species. For example the nuthatch (*Sitta eurapaea* L.) occurs only in parts of woodland with old deciduous trees (with holes) for building its nest, while the willow warbler (*Phylloscopus trochilus* L.), as a ground breeder, prefers young open parts of deciduous woodland with some undergrowth.

For maintaining biodiversity at a high level it will be necessary that biotopes should not become isolated to the extent that many indigenous species can no longer exchange individuals. Therefore, several biotope types should be maintained in a proper setting of a network which makes the exchange of individuals of species with a poor dispersal capacity possible. Our success at meeting the challenges of protecting biological diversity in urban areas is a good measure of our commitment to protect ecosystems and species worldwide (Adams et al. 2005).

GREEN INFRASTRUCTURE

Water ways, like the river Wisła, as well as roads and railways to other towns, are important determining factors for the way a city expands. As a result the built-up area of Warsaw has a lobate outline: the areas in between the built-up offshoots are relatively green. These so-called green wedges can function as a corridor for the dispersal of species from the outskirts to the centre of the city. However, there are many barriers to pass, like roads and railways. This is especially difficult (or impossible) for species which cannot fly. On the other hand many of these species can disperse lengthwise along verges of roads and railways. In this respect broad verges, if properly managed, can function as habitat and corridor for characteristic species (Mabelis 2000b). Such verges are part of the green infrastructure of the city, together with nature reserves, parks, allotment gardens and cemeteries.

A proper urban green infrastructure contributes to the biodiversity of the city and makes it more attractive as a residence. Its contribution to the species richness depends upon the size, quality and configuration of green areas. The presence of some relief adds to biotope differences, e.g. the west side of the old river bed is marked by a 10–25 m high escarpment, along which some parks are situated on the transition of the low river terrace (with wet areas) to the relatively high moraine plateau: an ideal situation for the establishment of a green corridor (Wolski 1999, Szulczewska & Kaliszuk 2003).

Part of the green infrastructure of Warsaw is connected with a blue infrastructure: the Wisła river with its adjacent riparian forest, the streams which flow into the river and the oxbow lakes, which are remnants of the old river bed. Species which are living in (or near) water have a higher survival probability if these waters are part of a habitat network, that is to say if they are not only suitable as habitat, but if they can also function as dispersal corridor or stepping stone.

For estimating the survival probability of species a distribution map of their habitat is needed. For good dispersing species the total habitat area will be most important for their survival, while for poor dispersing species number, size and configuration of habitat patches will be crucial. In the next paragraphs area, connectivity and quality of habitat patches will be discussed, successively.

HABITAT AREA

In general the size of a local population will decrease if the area of its habitat patch will become smaller. This is most obvious in the case of territorial species which are evenly distributed over the habitat patch. The smaller the population the vulnerable it will be for temporary disadvantageous environmental circumstances (environmental stochasticity) and for random changes in numbers, due to natality, mortality and migration (demographic stochasticity). Moreover, loss of genetic information may occur if the size of a population will become very small. Species which need a large foraging area are most sensitive to habitat reduction. For example a breeding pair of the tawny owl (*Strix aluco* L.) needs a territory of 20–40 ha, dependent of the amount of food which is available. Consequently, the probability of the tawny owl to be present in a forest patch in Warsaw appeared to be greater the larger its area (Wilcoxon: $P<0.01$; data from Jabłoński 1991).

On theoretical grounds it is assumed that the minimum viable bird population will be at least 20 breeding pairs (Verboom et al. 1997). This implies that a viable population of tawny owls should have the disposal of a foraging area of 400 – 800 ha. In a city this cannot be realized in one large habitat area, but only in a network of habitat patches (woodlots), between which exchange of individuals is possible. Local populations should become extinct one after the other if there should be no immigration of individuals from other patches. In the case of the tawny owl immigration is still possible if the distance between habitat patches is less than 15 km (Mooij 1982). The regional persistence of the species depends upon the proportion between the extinction of local populations and the (re)colonization of empty habitat patches. The turnover of local populations depends upon the size and connectivity of the habitat patches, the dispersal capacity of the species and the permeability of the city landscape for the species. It is argued that in a situation where the habitat of a species is fragmented the total habitat area needed for the persistence of such a metapopulation should be much greater than in a situation where its habitat is not fragmented (Verboom et al. 1997). This will be especially the case for species with a poor dispersal capacity.

Stenotopic species, which are fastidious about habitat quality, are also sensitive to habitat reduction, because a decreasing proportion between area and perimeter may affect its habitat quality more severely, due to increasing deteriorating effects from its surroundings. On the basis of distribution data of stenotopic forest carabids it is concluded that a patch of woodland with a diameter of less than 80 m is unsuitable for them (Mader & Mühlenberg 1980). This may mainly be due to negative influences from the surroundings on the microclimate of the patch, although other factors may play a role as well, like pollution, disturbance and dunging (by dogs). In Warsaw the butterfly *Maculinea teleius* Bgstr. is threatened by habitat reduction and even by disappearance of its habitat. The caterpillars of this rare butterfly are dependent on *Sanguisorba officinalis* L. as food-plant and on nests of *Myrmica* ants for their hibernation. The butterfly is protected by law, but will disappear from Warsaw as the plan to build houses on that location will be realized.

A reduction of habitat area will generally result in a decrease of stenotopic species, while eurytopic species, with a wide ecological amplitude, will become more common. In Warsaw it is found that the species composition of different invertebrate groups will shift to more common species, the smaller the area of the habitat, as found in carabid beetles (Czechowski 1981a), cockchafers (Kubicka 1981), leafbeetles (Wąsowska 1981, 1986), noctuids (Wegner 1982, Winiarska 1986), bees (Banaszak 1982), wasps (Skibińska 1978, 1982a, 1986b), digger wasps (Skibińska 1982b, 1986ac), parasite wasps (Sawoniewicz 1982, 1986), ants (Pisarski 1982b), flies (Bańkowska 1981abcd, Draber-Mońko 1981abcd, Durska 1981, Trojan 1981b), midges (Wegner 1982) and harvest-spiders (Czechowski et al. 1981).

The conclusion is that habitat loss, as a result of the reduction or disappearance of green areas, will lead to the extinction of local populations of species and may even lead to their disappearance from the city.

HABITAT CONNECTIVITY

Local populations of species fluctuate in numbers. They will eventually become extinct, unless they can be rescued by immigrating individuals from other habitat patches (Brown & Kodric-Brown 1977, among others). The immigration rate of a habitat patch depends upon the reproduction and dispersal capacity of the species, the distance to the nearest occupied habitat patches and the resistance of the area in between (habitat connectivity). A species can persist in a city as long as the extinction of its local populations can be compensated by the colonisation of unoccupied habitat patches. This may be possible if the patches are connected. In other words if they are part of a habitat network.

Species with a good dispersal capacity can reach all parts of a city. The environment will select where they will occur. Part of these species, which are fastidious for habitat quality, may be useful as indicators for deterioration of the environment.

Among the good dispersers are not only species which are able to fly, but also species which can be transported by the wind over long distances (e.g. spiders and seeds of anemochorous plants), species which can be easily transported by mammals (e.g. parasites and seeds of zoochorous plants) and species which can be transported by water (e.g. fishes and seeds of hydrochorous plants).

Most bird species can fly very well and can reach all parts of a city. Even relatively poor dispersers, like pheasant (*Phasianus colchicus* L.) and partridge (*Perdix perdix* L.), are able to colonise isolated habitat patches in a city: the pheasant was observed on fallow land in the centre of Warsaw rather soon after the species was introduced in a park at 2.5 km distance (Luniak 1983). Early in the morning, when there is less traffic, it will be able for the species to cross roads. Most bird species, which are adapted to the urban environment, like blackbird (*Turdus merula* L.), house sparrow (*Passer domesticus*), starling (*Sturnus vulgaris*) and jackdaw (*Corvus monedula*), cross busy roads regularly in daytime. In Warsaw it is even observed that a golden oriole (*Oriolus oriolus* L.) crossed a busy road (Luniak 1981, Mabelis, unpubl.). This species breeds rarely in cities and is rather shy. It is stated that the distance of a park to the city centre has no significant effect on the composition of its breeding population (Luniak 1983). The composition will be mainly determined by the diversity of vegetation types (ecosystems). However, the probability that a particular species will breed in a park depends upon the total habitat area within the park and the connectivity of the park with breeding areas elsewhere.

Many flying invertebrates can disperse very well through a city, especially small insects like aphids, flies, bees, wasps, bumblebees, ant queens, butterflies, dragon flies and macropterous beetles. However, even these flying insects need green elements as stepping stones and corridors for their dispersal. For example the cinnabar moth (*Tyria jacobaea* L.) could disperse far into the city of London via road- and railway verges, on which food plants of the caterpillar grow (Plant 1994). Also long winged grasshoppers are dependent on linear habitat elements for their dispersion in a built-up environment: the oak bush-cricket (*Meconema thalassinum* Degeer) disperse along lanes with oak trees and the great green bush cricket (*Tettigonia viridissima* L.) along road and railway verges with a ruderal vegetation. An interruption of such a corridor by a road, canal or bridge, is not an insurmountable barrier for most flying insects, although it may reduce their dispersion.

Most species which live in dynamic environments, like wasteland, have a good dispersal capacity. It means that extinction of local populations of these species, due to succession of the vegetation or to cultivation, can be compensated by the colonisation of habitat patches, which become available elsewhere in the city. However, Crowe (1979) found less flowering plants in more isolated wastelands. It appears that even the colonisation probability of good dispersing species is affected by the distance between habitat patches.

For animals which can only walk or creep, roads, parking places and water ways are important dispersal barriers. Nevertheless, small mammals, like the house-mouse (*Mus musculus* L.), the longtailed fieldmouse (*Apodemus sylvaticus* L.) and the brown rat (*Rattus norvegicus* Berkenhout) can reach all parts of a city (Klausnitzer 1989, Sukopp 1990, Szacki et al. 1994). Even larger mammals, like the fox (*Vulpes vulpes* L.) and the beech marten (*Martes foina* Erxleben), penetrate a city sometimes very deeply at night (Harris 1986, Klausnitzer 1989, Sukopp 1990). These species disperse best in city quarters with large, joining gardens and in green strips with bushes. Also mice and voles, which avoid paved roads (Mader & Pauritsch 1981), use such green structures during dispersal (Liro & Szacki 1987, 1994; Szacki et al. 1994). A subterranean species , like the mole (*Talpa europaea* L.), can disperse via road verges and joining gardens, although structure and food supply of the soil is decisive if he will use them (Haeck 1969). Moles avoid built-up and paved areas. Young ones may cross an asphalt road now and then, but often they cannot reach isolated gardens and parks (Sukopp 1990). Hedgehogs (*Erinaceus europaeus* L.) can disperse in a city via road verges, parks and gardens. They cross traffic roads at night, which causes many traffic victims. Consequently, they cannot reach isolated areas (Klausnitzer 1989). That holds also for the squirrel (*Sciurus vulgaris* L.), which is active in daytime and will cross a traffic road rarely (Klausnitzer 1989, Sukopp 1990). The result is that less mammal species occur in the centre than in the outskirts of a city.

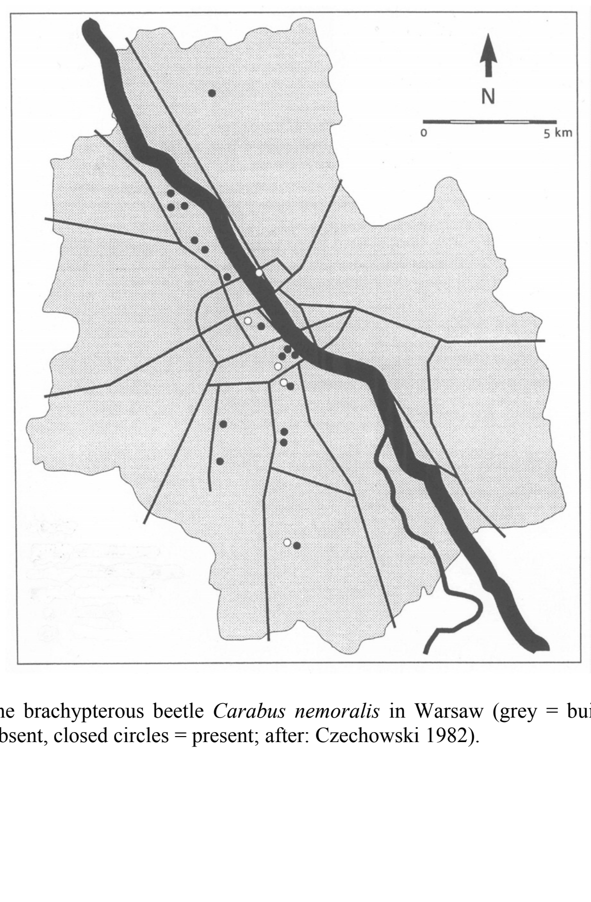

Fig. 1: Occurrence of the brachypterous beetle *Carabus nemoralis* in Warsaw (grey = built-up area, black lines = barriers, open circles = absent, closed circles = present; after: Czechowski 1982).

Roads are also important barriers for amphibians and reptiles. Consequently, reptiles occur generally only in the outskirts of a city. However, amphibians can penetrate a city by means of water courses and ponds (Mazgajska 1996, among others). This applies especially to the common toad (*Bufo bufo* L.) and the small water-salamander (*Triturus vulgaris* L.) (Sukopp & Werner 1987).

Invertebrate species, which cannot fly, like brachypterous carabid beetles, generally will not cross a paved road (Mader 1988). Consequently, most of these species don't occur in the city centre (Czechowski 1982). An exception is *Carabus nemoralis* Müll., a forest species, which occurs on several places in the centre of Warsaw (Fig. 1). These local populations may be relict populations, but it is also possible that the species is able to penetrate the city via allotment gardens, road and railway verges with a bushy vegetation. The species was not found in green strips, which are mowed or raked regularly (Czechowski 1982).

Not only nature reserves and parks can be used by species as dispersal corridors and/or as habitat, where they can reproduce, but also allotment gardens, cemeteries, road and railway verges. For most invertebrate species which disperse over short distances, the availability of habitat will be conditional for their occurrence in such anthropogenic ecotopes. Therefore it is important to pay also attention to the ecological quality of these green areas.

HABITAT QUALITY

Many biotope types can be distinguished in a city, ranging from artificial to natural. The quality of natural biotopes generally decreases to the centre of a city, but this does not hold for artificial biotopes: some species occur mainly in the city centre, where old buildings are present, e.g. swift and kestrel (Luniak et al. 2001). Biotope quality can be maintained (or improved) by proper planning and management. The management of a few biotope types will be discussed: woodland, grassland, wasteland and water.

Woodlands are relatively stable: they have a rather constant microclimate. In such an environment stenotopic forest species can be expected. However, stability of woodlots may be less in the centre of a city than in the outskirts, where it will be less intensively used and managed. Less forest species were found in parks of Warsaw than in its surroundings in case of carabid beetles (Czechowski 1979, 1982), weevils (Cholewicka 1981), rove beetles (Klausnitzer 1989), julides (Jędryczkowski 1982), spiders (Krzyżanowska et al. 1981), springtails (Sterzyńska 1982) and several other groups. This is not only due to the more isolated position of woodlots for species with a poor dispersal capacity, but also to disturbance and intensive management. For example, raking leaf litter intensively has a serious reducing effect on the species richness of snails (Klausnitzer 1987, 1989), worms (Kasprzak 1986), julides (Jędryczkowski 1982), spiders (Krzyżanowska et al. 1981), cicada (Chudzicka 1982, 1986), carabid beetles (Czechowski 1982) and parasite wasps (Garbarczyk 1982). Locally the species spectrum of carabid beetles, click beetles and springtails shifted towards underground living species, due to intensive measures of management (Czechowski 1982, Nowakowski 1982, Sterzyńska 1982, 1987), while the spectrum of ant species shifted towards species which live in trees (Czechowski et al. 1990). The poverty of invertebrates on such localities is of great disadvantageous for many mammal species and birds (Dickman 1987, Mulsow 1982, respectively; see Fig. 2). For example the robin (*Erithacus rubecula* L.) breeds only in parks of Warsaw where leaf litter was not raked, while birds which breed on the ground or in bushes prefer localities where management is lacking or very extensive (Luniak 1981).

The removal of old trees and dead wood, reduce flora and fauna of the forest (Fig. 3). Consequently, less species of longhorn beetles were found in woodland within Warsaw than in its surroundings (Burakowski & Nowakowski 1981b). The forest fauna can also be impoverished by removing bushes and herbs, as ascertained for spiders, carabid beetles, snails and birds (Krzyżanowska et al. 1981, Czechowski 1982, Klausnitzer 1987, Luniak 1981, respectively). Mixed forest with a great structural diversity (vertically and horizontally) are richest in species. At places where the forest gradually fade into an open area with herbs and some bushes, a border vegetation can develop which offer habitat for a lot of species which prefer forest edges.

Grasslands in urban areas are often mowed frequently in order to keep them tidy or suitable for recreation activities. This holds not only for lawns in parks, but also for public gardens between flats. Consequently, these grasslands are poor in species. In parks with large grassland areas it is possible to enlarge the number of species by applying different mowing regimes on different localities: parts which are mowed frequently for intensive recreation and parts which are mowed once (or twice) a year for giving visitors the opportunity to enjoy flowers and insects (Fig. 4). By keeping these differences in management constant over years the number of species will increase, while the extinction probability of their local populations will decrease, due to spreading their extinction risk in space (Den Boer 1968, 1981). In short: local biodiversity can be enhanced by striving for diversity in space, while keeping the management constant in time. Flower-rich grasslands with a diversified structure are richest in species. They should be managed (mowed or grazed) extensively.

Wastelands are generally only temporary available for species. New wasteland will be colonised first by species with a good reproduction and dispersal capacity. Many of these pioneers are eurytopic and live rather short. A great deal of the pioneer plants are annuals and most insect species are polyphagous. In the coarse of time the proportion of perennial plants will increase and consequently the number of food specialists among the plant- eating insects. Such vegetations possess a rich entomofauna: at least 90 insect species are more or less dependent on the creeping thistle (*Cirsium arvense*`-Scop.) and related species (Zwölfer 1965, Redfern 1983) and up to 100 insect species feed on such common species as *Artimisia vulgaris* L. and *Tanacetum vulgare* L. (Klausnitzer 1968). Wastelands are good foraging areas for seed- and insect-eating birds. They are also good habitat for the house mouse (*Mus musculus* L.), longtailed fieldmouse (*Apodemus sylvaticus* L.) and common vole (*Microtus arvalis* Pallas) and this makes wastelands popular as foraging area for birds of prey and owls (Klausnitzer 1987).

However, habitat quality of wastelands decreases if they are used as dumping place for rubbish. Especially chemical waste can impoverish the fauna, e.g. heavy metals are harmful to springtails and other saprophagous species (Sterzyńska 1987). Also synthetic substances are detrimental for the soil fauna (Kohsiek et al. 1994).

Railway emplacements contribute also to the biodiversity of a city. The flower-rich vegetation on such nutrient-poor soils offers suitable habitat for many insect species, like digger bees and digger-wasps, under the condition that no pesticides will be used.

Water courses and ponds make the urban environment more attractive. Their contribution to biodiversity depends for a great deal on their water quality. Enrichment of the water with nutrients, like nitrogen and phosphorus, should be opposed as much as possible. The presence of a riparian vegetation will have a purification effect on water quality (Tourbier & Pierson 1976). Such a vegetation can be developed by making the slope of the border less steep or even locally flat. The diversity of a riparian vegetation can be enlarged by creating an irregular shoreline with variation in cross direction, as well as in length direction (Adams et al. 2005). A diverse riparian vegetation offers more bird species a breeding place, as well as habitat for water animals, like snails, dragonflies (*Odonata*), mayflies (*Ephemeroptera*) and many other invertebrates. A few streams in Warsaw are canalized to get rid of the storm water runoff as quick as possible. However, retaining the effluent could give opportunities for natural purification before it runs into the river Wisła (Fig. 5).

Figs 2–7. Green infrastructure of Warsaw; 2 – Raking leaf litter intensively impoverishes flora and fauna, 3 – Dead wood offers habitat for many species, 4 – Flower-rich grassland which is mowed only once a year, 5 – Canalized stream, 6 – Flower-rich road verge as habitat and foraging area of insects, 7 – Railway verge as habitat and corridor for species.

Planning and management

Biodiversity in a city can be kept at a high level by implementing a sustainable green infrastructure. In Warsaw the concept of an Urban Natural System was presented in the Warsaw Master Plan of 1992. The aim was to protect the most valuable green areas. However, a comparison with the adjusted Plan of 2001 it reveals that some valuable green areas vanished (Szulczewska and Kaliszuk 2003). Protection of green areas on the level of the city should be effective, but as remarked in the Warsaw Master Plan of 1990 (p. 32): the problem of uncontrolled development will be particularly difficult to solve correctly in Warsaw, where the districts have an important voice in the matter.

Biotope patches which will become smaller and more isolated will loose species: first of all species, which are sensitive for habitat fragmentation. In practice it will be possible to increase habitat area of some target species of nature conservation by adjusting measures of management. For example if the marshland of Zakole Wawerskie would be managed properly, then the habitat area of many characteristic and rare marshland species will increase, and hence their survival probability.

In some cases it will also be possible to increase the survival probability of species by improving the connectivity with other habitat patches by planning and implementing corridors, e.g. by constructing eco-tunnels and a walking ridge in culverts.

The river Wisła and its banks, which are partly covered by riparian forest and flower-rich meadows, is a good example of a blue-green corridor. If properly managed it will have an important habitat and dispersal function for water and marshland species. Another example is the planned system of linear parks along the escarpment of the old riverbed in southern Warsaw (Skarpa Ursynowska). It is also desirable to plan green corridors along streams, although such ideas are not always implemented during the execution of a development plan (for Białołęka Dworska, see: Bańkowska et al. 1985). In practice the concept of an Urban Natural System will be part of a coherent package of objectives, principles and priorities for the desired quality of green areas in the public domain. The question is how the implementation of an ecological network of habitats, corridors and stepping stones for the survival of species can be integrated in the planning of urban projects. In many cases it will be possible to link the ecological network with a recreational network, a traffic network and a network for proper water management (Tjallingii 2003). For example broad verges along roads and railways can be used as corridors by cyclists and/or pedestrians, as well as by animal species (Mabelis 2004, Figs. 6 & 7). Another example: wasteland can be used by plants and animals as habitat and/or stepping stone, but also by children to play and experience nature. The value of wasteland for these functions is generally underestimated.

In order to keep biodiversity at a high level monitoring of nature quality is necessary. A monitoring programme can be part of an Ecological Policy Plan of the city. Monitoring has two functions: to determine if policy targets concerning biodiversity are attained (evaluating or controlling function) and to signalize unexpected changes in environmental quality (signalizing function). For both functions it will be necessary to relate measured data to possible causes of changes in environmental quality (diagnostic capacity). So it is not enough to collect data, but they should be analysed and interpreted (Fig. 8). For the interpretation it is desirable to measure also possible causal factors, like pollution and recreation pressure. The following steps should be described in a monitoring programme:

- targets for measurements: data for comparing them with standard values or to establish trends;
- objects (e.g. species) and variables (e.g. size of local populations), which should be measured;
- sample strategies: localities, method and frequency of sampling;
- organisation structure: description of responsible executors who will collect, analyse and interpret the data.

For the registration of trends in environmental quality a map on which the distribution of different ecosystems (biotope types) is given will be helpful for measuring the total area per biotope type, as well as the size and configuration of biotope patches.

The quality of biotope patches can be measured by describing the composition and structure of their vegetation and in the case of water its clearness and the presence of a submersed and emerged vegetation. The nature quality of biotopes can be kept at a high level by maximizing the number of species which are characteristic for that biotope type (Mabelis

2000a). For the maintenance of characteristic and rare species in the city it is desirable to collect yearly data about the population size of a few representatives.

Changes in the size and configuration of green areas will affect the liveability of a city for citizens and its viability for plants and animals. Many green areas in Warsaw have no destination at the moment. For city planners it will be useful to make predictions about the consequences of the expansion of built-up areas for the survival of species, because it will make it easier to make a choice between alternatives. For this aim species can be selected which are easily detectable, which differ in survival strategies and which belong to different functional groups (e.g. reducers, herbivores, carnivores).

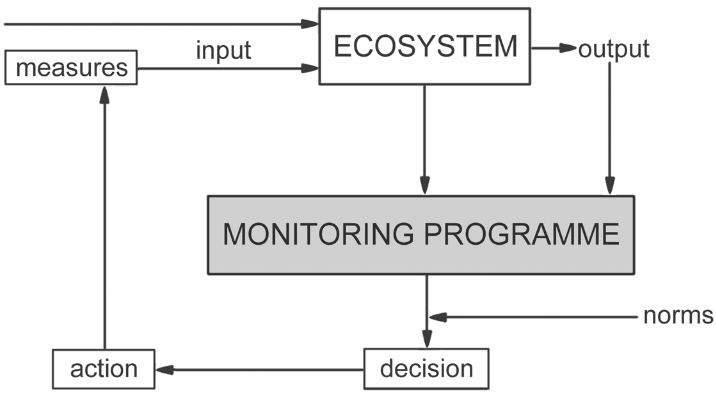

Fig. 8. Controlling function of a monitoring system.

For people who are responsible for the management of green areas it will be good if they realise the consequences of methods used for the species richness of those areas: it may lead to more environmental friendly decisions. A problem is that many green areas in Warsaw are used by some people as dumping places for their rubbish. It concerns not only verges along roads and railways, but also nature reserves. In order to prevent pollution a good communication between responsible authorities and citizens is necessary. Citizens could be stimulated by authorities and non-governmental organisations (NGO's) to care for nature in the environment where they are living. However, this is only possible if the City Council, local authorities and managers of urban green will feel responsible for the maintenance of a high level of biodiversity in the city.

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STRESZCZENIE

[Infrastruktura zieleni miejskiej i jej różnorodność biologiczna na przykładzie Warszawy]

Szybki rozwój miast związany jest z zanikaniem lub degradacją terenów zielonych, poddanych coraz silniejszej presji urbanizacyjnej. Zmiany wielkości i rozmieszczenia zieleni miejskiej będą wpływać na jakość życia mieszkańców, jak i na możliwość przetrwania w tym środowisku wielu gatunków roślin i zwierząt. Odpowiednie zarządzanie, nie tylko wodą, energią i odpadami, lecz również terenami zielonymi miasta, jest niezbędne do zapewnienia optymalnych warunków do życia w tym środowisku. Obszar terenów zielonych, połączenia między nimi i jakość tych środowisk mają kluczowe znaczenie dla przeżywalności wielu gatunków. Dzięki zachowaniu rozbudowanej sieci terenów zielonych, możliwa będzie wymiana osobników należących do gatunków o słabych możliwościach dyspersyjnych. Warunkiem zdobycia publicznego wsparcia na utrzymanie zieleni miejskiej są dobre kontakty między odpowiedzialnymi władzami administracyjnymi a mieszkańcami. Dla utrzymania różnorodności biologicznej na wysokim poziomie niezbędne jest monitorowanie jakości środowiska. Program monitoringu powinien być częścią planu polityki ekologicznej miasta.

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