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Urban Mammals

Robert McCleery

Abstract

There is a clear relationship between mammalian diversity and the degree of urbanization of the landscape. As urbanization increases, mammalian diversity is lost. The loss of species in urban areas is generally attributed to habitat degradation and fragmentation, the loss of vegetation to impervious surface, and the simplification of vegetation. Mammals with large body sizes and corresponding large movement and range patterns, predators, interior species, and habitat specialists all appear to be sensitive to urbanization. On the other hand, a number of omnivores, generalists, and medium-size carnivores have been able to utilize the ample resources of the urban environment. Mammalian populations that have adapted to the urban environment commonly have higher densities, higher rates of survival and reproduction, and lower rates of dispersal than their rural counterparts. Additionally, urban populations also frequently show different behaviors from rural populations, including reduced responses to humans, altered activity periods, smaller ranges of movement, and different territorial behaviors. Urban mammals also have been shown to alter their diets to consume more anthropogenic foods and to use buildings, culverts, and bridges for shelter and the rearing of young. However, the concentrated nature of urban resources and the high population densities of urban adapted mammal population make them more susceptible to disease outbreaks and parasites. The moderately developed areas with anthropogenic food, high net primary production, and structures for shelter probably hold the most potential for urban conservation efforts of native mammals.

As the dominant ecological force on the planet, humans have altered more than 75% of the ice-free surface of the globe (Ellis and Ramankutty, 2008). The most intensive alterations to Earth's surface have come from the creation of cities. Cities play a vital role in human culture as centers for commerce, residence, entertainment, and social interactions. Currently, more than 50% of the planet's human population lives in cities and more than 65% of the population is projected to live in urban areas by 2045 (United Nations, 2008). Cities account for only 2.4% of the Earth's surface (Millennium Ecosystem Assessment, 2005), but because of the intensity and magnitude of this land use, it has a disproportionate influence on regional and global ecological systems and processes (Collins and Kinzig, 2000).

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The landscape, along with the biotic and abiotic features of urban environments, can vary immensely between cities, and even among neighborhoods in the same city. Nonetheless, we can characterize urban environments as areas of dense human populations, buildings, impermeable surfaces, and introduced vegetation with high concentrations of food, water, energy, materials, sewage, and pollution (McDonnell and Pickett, 1990; Pickett et al., 2001; Adams et al., 2006). From a landscape perspective urban systems are mosaics of residential, industrial, commercial, and infrastructure interspersed with green areas (Breuste et al., 2008). For mammals these important green areas often come in the form of a patchy network of lawn, parks, trails, golf courses, cemeteries, and a few areas of native vegetation.

How mammalian populations and communities respond to the urban environment, among other factors, is a function of the specific features of a particular urban environment and of the scale of the surrounding urbanization. Although oversimplified, a useful way to conceptualize a city is as a gradient of development intensity (McDonnell and Pickett, 1990). At the core of a city most vegetation has been replaced by impervious surfaces, there are high densities of inhabitants and buildings, and there is negligible net primary production. Moving away from the city core, impervious surfaces and the numbers of buildings and residences slowly decrease, and the landscape eventual changes to rural or wildlands. This simplified pattern of urbanization helps us to generalize how mammals respond to changing ecological processes and features along a changing gradient of land uses from the city center to rural areas. For example, in the city center mammals' food resources come from garbage, and they utilize buildings and culverts for den sites. Alternatively, further along the gradient in suburban areas, watered and fertilized lawns provide mammals with ample food from vegetation and shelter in the form of trees and shrubs. Some of the other important features that change along the urban–rural gradient that are believed to influence mammal populations are roads, climate, and the density of predators.

Regardless of where along the urban–rural gradient we look, mammals can be found, occurring in every part of the urban environment. With one-half of the world's population living in urban areas, this is where most humans will observe and interact with other mammalian species. The interaction of humans with mammals has implications for health, quality of life, education, aesthetics, and conservation. In this chapter I will begin by exploring how mammalian communities change with urbanization. Then I will investigate how urbanization has changed the demographics, movements, behaviors, diet, physiology, and health of mammalian populations. I will conclude the chapter by showing how mammalian populations utilize the anthropogenic features of the urbanized environment and examining the potential for the conservation of mammals in urban environments.

Mammal Communities in Urban Areas

Urbanization has been detrimental to the mammalian diversity on local and globe scales. Urban development is potentially the leading cause of endangerment and expatriation of native mammal species (Czech et al., 2000; McKinney, 2002). In areas such as Australia less than one-half of the native mammal species still occur in and around urban areas (Ree and McCarthy, 2005; Tait et al., 2005).

Most researchers have shown a clear relationship between mammalian diversity or richness and the amount of urbanization—as urbanization increases mammalian diversity is lost (e.g., McKinney, 2008). The loss of species in urban areas is generally attributed to habitat degradation and fragmentation, the loss of vegetation to impervious surface, and the simplification of vegetation (McKinney, 2008). Moreover, the introduction of species and persecution of mammals has also played a role in the loss of mammalian diversity in urban areas (Matthiae and Sterns, 1981; Tait et al., 2005). Nonetheless, not all research has shown a pattern of declining diversity with increased urbanization. Racey and Euler (1982) found that small mammal diversity increased at moderate levels of development. They attributed this finding to the habitat heterogeneity and edge effects created by clearing forest lots for cottages.

The mammalian species that have been the most sensitive to urbanization generally have similar morphologies or life history strategies. These sensitive mammals often have large body sizes and corresponding large movement and range patterns, such as bison (*Bison bison*) or elk (*Cervus canadensis*). Similarly, large predators and those mammals that have been persecuted are rarely found in urban areas, including wolf (*Canis lupus*), bear (*Ursus* spp.), and mountain lion (*Felis concolor*) (Matthiae and Sterns, 1981; Dickman, 1987; Vandruff et al., 1996). Additionally, interior species and habitat specialists, like fisher (*Martes pennant*) or lynx (*Lynx canadensis*), appear to be vulnerable to urbanization.

Although diversity often decreases with development, some mammals take advantage of favorable conditions within the matrix of lawns, houses, parks, gardens, and natural areas found in urban areas outside of the city core. Refuse, supplemental food, ornamental plants, and highly productive lawns often provide plentiful food resources for the mammals able to exploit them (McKinney, 2002). In fact, parks and lawns can have more net primary production than the neighboring wildlands of the region (Imhoff and Tucker, 2000).

The mammalian species found utilizing the lawns and other features of moderately developed areas are termed *urban adapters* (McKinney, 2002). Urban adapters are often generalist, and in nonurban areas they commonly thrive on edges or in savanna habitats that are structurally similar to many urban backyard, forest, and park matrices (McKinney, 2002). Urban adapters utilize many of the food resource available around human development, including ornamental plants, gardens, garbage, and supplemental food. Common urban adapted mammals include burrowing species—moles (*Talpidae*), groundhogs (*Marmota monax*), armadillos (*Dasyopus novemcinctus*)—which are capable of finding refuge, avoiding human in their burrows, and finding shelter under porches and houses. They can also take advantage of rapidly growing grasses, ornamentals, and ample invertebrate populations found on urban lawns (Falk, 1976; McKinney, 2002). Medium-size omnivorous and carnivores, such as opossums (*Didelphis virginiana*), raccoons (*Procyon lotor*), foxes (*Vulpes* spp.), and coyotes (*Canis latrans*), have also been successful urban adapters, in part because of the elimination of large predators (Crooks and Soule, 1999). Omnivorous predators can also become highly adept at utilizing human food resources, such as trash, gardens, and bird seed (McKinney, 2002).

The mammals that are capable of living in even the most developed portion of the urban environment are termed *urban exploiters* or *synanthropes*. They are a homogenous group of early successional species that are rarely native to a

region and highly adapted to urban environments. They are usually omnivorous, and their populations are dependent on human resources, with little reliance on local vegetative communities (Nilon and Vandruff, 1987; McKinney, 2002). Urban exploiters commonly found in the city core include house mice (*Mus mus*), black rats (*Rattus rattus*), feral cats (*Felis catus*), and Norway rats (*Rattus norvegicus*).

While the creation and expansion of cities has removed many native mammal species, invasive species have been filling the ecological vacuum to replace them. It has been shown that as urbanization increases, the portion and density of nonnative mammals also increases (Mackin-Rogalska et al., 1988; McKinney, 2002; Tait et al., 2005). This is helping to create a situation where the same few species can be found in the cores of cities worldwide (McKinney 2006).

Demographics

Populations of mammalian species that have been able to utilize the urban environment often show considerably different demographics than their rural counterparts. Most notably, many urban adapted species, including white-tailed deer (*Odocoileus virginianus*) (Coté et al., 2004), raccoons (Prange et al., 2003), gray squirrels (*Sciurus carolinensis*) (Hadidian et al., 1987), striped field mice (*Apodemus agrarius*) (Gliwicz et al., 1994), coyotes (Fedriani et al., 2001), and foxes (Harris and Smith, 1987), have all shown increased densities in urban areas. In some cases the densities of urban adapters have been extraordinary. For example, raccoons in nonurban areas rarely exceed 20 km⁻², but in urban environments they have recorded densities up to 333 km⁻² (Lotze and Anderson, 1979; Riley et al., 1998). Similarly, gray squirrels usually do not exceed 3 ha⁻¹ in nonurban areas, but densities greater than 50 ha⁻¹ have been recorded in an urban park (Koprowski, 1994; Hadidian et al., 1987). Population densities of urban exploiters can also be astronomically high. The core areas of numerous cities worldwide have rat densities of more than 3000 km⁻² (Keeling and Gilligan, 2000).

The specific demographic reasons for high densities of urban mammals vary by population and species but appear to be from a combination of increased survival and fecundity rates, and decreased rates of dispersal. What has been less clear, are the specific mechanisms causing the population demographics of urban populations to differ from their rural counterparts.

The survival rates of many mammalian populations have been shown to be higher in urban environments. One of the primary reasons given by researchers for this phenomenon is the decrease in potential sources of mortality and specifically a reduction in the risks of predation and hunting (Gliwicz et al., 1994; Etter et al., 2002; Prange et al., 2003; McCleery et al., 2008). For game mammals such as white-tailed deer, it is also logical to believe reductions in and restrictions to hunting in urban areas have helped to increase survival rates (Etter et al., 2002). Crooks and Soule (1999) showed that habitat patches without large predators (i.e., coyotes) had twice the number of mammalian mesopredators common in urban environments, presumably because coyotes weren't eating them or restricting their movements. Similarly, research has shown that urban fox squirrel (*Sciurus niger*) were less likely to be predated in urban environments (McCleery et al., 2008), and high density populations of urban striped field mice were less likely to be present in raptor and owl pellets in the inner city (Gliwicz et al., 1994). Nonetheless, it is also possible that some smaller rodents might see a reduction in survival in areas of high cat activity. Cat abundance has been shown

to be negatively correlated with the densities of some small mammals (Baker et al., 2003), and in one study, 69% of the prey items brought home by house cats were mammals (Woods et al., 2003).

The sources of mortality for mammals are often considerably different for urban populations. The greatest source of mortality for many urban adapted mammals is road kill. Collisions with vehicles has been shown to be a major source of mortalities for urban white-tailed deer (Etter et al., 2002; Lopez et al., 2003), raccoon (Prange et al., 2003), fox squirrel (McCleery et al., 2008), coyote (Gehrt, 2007), and fox populations (Gosselink et al., 2007). Disease outbreaks are also a common cause of mortality in urban areas, likely due to the high densities found for many urban mammal populations (Gosselink et al., 2007; Prange et al., 2003).

There are at least two other interesting patterns that researchers examining urban mammals survival rates have found. In several cases the survival rates of rodents have been higher during the winter months, a time when harsh condition should reduce survival (Gliwicz et al., 1994; McCleery et al., 2008). One explanation is that the warmer microclimate and a plentiful supply of food found in urban areas helps to mitigate the effect of winter (Andrzejewski et al., 1978). Additionally, researchers have found that urban male white-tail deer (Lopez et al., 2003) and fox populations (Gosselink et al., 2007) had lower rates of survival than urban females. It is possible that the more extensive movement patterns of males makes them more susceptible to road kill, a major cause of mortality for both populations.

In addition to higher rates of survival, many urban adapted mammal populations have shown increased reproductive success. Urban black bears (*Ursus americanus*) and raccoons appear to have larger litter sizes than rural populations, with urban bears giving birth to up to three times more cubs than bears in wildlands (Beckmann and Berger, 2003; Prange et al., 2003). Both of these species feed on highly caloric garbage in urban environments, which might provide a mechanism for increased litter sizes. Urban fox squirrel populations appear to have litter sizes comparable to rural populations, but unlike rural populations, most females in an urban population have been shown to have more than one litter annually (McCleery, 2009a). Similarly, urban striped field mice extend their breeding season later into autumn in the urban environment and appear to reach sexual maturity quicker in urban areas (Andrzejewski et al., 1978; Gliwicz et al., 1994).

Many urban populations have even sex ratios or ratios that match rural populations. Nonetheless, some urban mammalian populations, such as striped field mice (Andrzejewski et al., 1978), foxes (Harris and Smith, 1987), and black bears (Beckmann and Berger, 2003), have shown a bias toward males. On the other hand, a population of urban white-tailed deer has been dominated by females; however, this is likely due to differential survival rates of the sexes because fetal sex ratios of the population have been skewed toward males (Lopez et al., 2003).

Increased rates of reproduction in urban mammal populations can lead to a surplus of juveniles if they survive. In general, juvenile mammals have an increased risk of mortality from weaning to adulthood. However, as with adults, survival of young mammals has increased with urbanization for fox squirrel (McCleery, 2009a), white-tailed deer (Peterson et al., 2004), and raccoon (Rosatte et al., 1991). Increased survival of juveniles leaves many urban mammal populations

with a surplus of juveniles that can either be recruited into the population or can disperse to other populations.

Movements

Decreased rates of dispersal for surplus juveniles have commonly been cited as a reason for increased densities of mammal populations in urban areas (Etter et al., 2002; Prange et al., 2003; Gliwicz et al., 1994). Not only do there appear to be less-frequent dispersals from urban habitat patches for some mammals, but the distances dispersed might also be shorter in the urban environment (Etter et al., 2002; Harris and Trehwella, 1988). Limited dispersal or reciprocal site fidelity in urban mammals has been hypothesized to be a function of the harsh environment surrounding urban habitat patches (Etter et al., 2002) and the high quality food and resources consistently available in the urban environment (Prange et al., 2003). Undoubtedly, the dominant features of urban landscapes, roads and development, pose a barrier to the movements of many urban mammals. Roads have been shown to restrict the movements of small mammals, such as hedgehogs (*Eri-naceinae*) (Rondinini and Doncaster, 2002), woodrats (*Neotoma* spp.) (McCleery et al., 2006a), and white-footed mice (*Peromyscus* spp.) (Merriam et al., 1989). Roads might present less of a barrier to medium-size mammals, but their movements might still be restricted by larger highways (Prange et al., 2004; Gehrt, 2005; Riley, 2006). Even large mammals such as white-tailed deer appear to avoid highways with more than eight lanes and dense development (Etter et al., 2002). Regardless of these barriers, urban mammals still disperse across the urban matrix and in at least two studies, researchers have found that dispersing juveniles in urban areas ran a higher risk of mortality due to roadkill than juveniles dispersing from rural areas (Beckmann and Berger, 2003; Etter et al., 2002).

In this manner the urban environment may pose an ecological trap for some urban mammal populations. Urban areas can have a consistent source of high quality food and reduced risks of predation, allowing mammals to have relatively high rates of reproduction. However, when this surplus of juveniles disperses out of these high quality patches, a disproportionate number of young can be lost to collisions with automobiles or to other hazards of the urban environment. Similarly, a number of authors have suggested that urban mammal populations may have source–sink population dynamics (Dickman and Doncaster, 1987; Harveson et al., 2004; Gosselink et al., 2007; McCleery, 2009a). The sources come from high quality urban patches, such as parks, remnant habitat patches, and restorations, and sinks can come in the form of lower quality urban areas, such as those lacking vegetation and having frequent disturbances and high levels of cat activity, or adjacent rural land with numerous predators and hunters.

Many researchers examining the ranges of mammals in urban environments have found that their ranges have been smaller and often more stable than nonurban populations (Etter et al., 2002; Beckmann and Berger, 2003; Prange et al., 2003; Harveson et al., 2007). Additionally, some urban mammals have been shown to have more complex and less uniform ranges, likely due to the heterogeneous nature of the urban landscape (Harrison, 1997). A possible explanation for the smaller ranges seen in urban mammals is that the patchy nature of the urban environment restricts the movements of urban mammals to areas with strict boundaries (Etter et al., 2002; Prange et al., 2004). Additionally, the clumped, abundant, high quality, and stable nature of resources in the urban environment

may help to concentrate the animal into smaller areas (Beckmann and Berger, 2003; Prange et al., 2004). A common finding from research of urban mammals is that they congregate in areas of their preferred resource, such as areas of shrubs, woodlots, picnic sites, and where garbage can be found, and they avoid areas with limited resources, such as ball fields and paths (Gliwicz et al., 1994; Beckmann and Berger, 2003; Prange et al., 2004). The dichotomous nature of habitat selection in urban mammals can lead to the clumped and uneven distributions found in some populations of urban mammals (Dickman, 1987; Gliwicz et al., 1994; Prange et al., 2004).

Territoriality

Examining social behaviors and the partitioning of resources, researchers of urban mammals have noted that urban population appears to differ from non-urban populations (Berger and Beckmann, 2003; Prange et al., 2004; Riley, 2006). Food (quantity, quality, and distribution), density and distribution of refugia, density of conspecifics, habitat features, mates, and predation pressure all influence to what extent animals become territorial or use social hierarchies to partition resources (Maher and Lott, 2000). Only when resources are at intermediate levels do the benefits of procuring them via territoriality outweigh the costs of defending them (Krebs and Davies, 1993). Likewise, individuals respond to population densities by showing territoriality at lower and intermediate levels, while abandoning areas at high levels, possibly due to intruder pressure and the effort needed maintain the territory (Maher and Lott, 2000). Thus, it should not be surprising that high densities of mammals in urban areas have led to increased range overlap and decreased territoriality, especially when there are large quantities of high quality anthropogenic food available (Harris, 1980; Beckmann and Berger, 2003; Prange et al., 2004). However, there are also features of the urban environment that might lead to increased territoriality. Not all resources in the urban environment are abundant. For example a shortage in large dead trees in the urban environment may lead to increased territoriality (especially for females) in a population of urban fox squirrels (McCleery, unpublished data, 2007). Additionally, there is a positive relationship between habitat complexity and territoriality, possibly because the cost of territoriality has been reduced by clear boundaries of demarcation (Maher and Lott, 2000). For example, urban fox squirrels use building to delineate ranges (McCleery, unpublished data, 2007) and bobcats (*Lynx rufus*) use roads to define their territories (Riley, 2006), so the heterogeneous nature of the urban environments may lead to more territorial behavior in certain cases.

Behaviors

There are at least two characteristics of the urban environment that should influence the behavioral choices made by mammals when balancing predation risks with foraging. First, as human activity increases toward the city center, it creates an almost constant predator stimulus for urban mammals. Even without the risk of predation, these disturbances may negatively alter an animal's behavior by increasing vigilance behaviors (Berger et al., 1983; Frid and Dill, 2002). The second factor of urbanized environments that should affect mammals' behavioral choices is a reduction in the risk of predation along the urban-rural gradient due to the elimination of or avoidance of predators in most urbanized areas (Blumstein,

2002; Adams et al., 2005), which hypothetically allows mammals to use more of the urban environment without need for vigilance behaviors. Some studies have shown reductions in mammals' responses to humans corresponding to the increased exposure of mammals to humans in developed areas (Reimers and Sigurd, 2001; Magle et al., 2005; Harveson et al., 2007; McCleery, 2009b). One of the most common and highly plausible explanations given for reduced responses to humans is habituation (McCleery, 2009b). *Habituation*, a decreased responsiveness to repeated stimuli, seems to provide a mechanism for urban adapted mammals to cope with the constant human induced predator stimuli and take advantage of the resources in an environment with a reduced risk of predation. It has also been shown that once animals habituated to humans they may also transfer this reduced response to other predator stimuli. McCleery (2009b) reported that urban fox squirrels that showed a reduced response to humans also showed a reduced response to hawk and coyote calls when compared with rural and suburban populations.

Human activity in urban environments has altered mammal's behaviors in other ways. A number of populations in urban environments have been shown to be active at different times than rural populations (Tigas et al., 2002; Riley et al., 2003; Gehrt, 2007). Coyotes, bobcats, and javelina (*Pecari tajacu*) showed reduced activity during daylight hours and increased nocturnal activity in areas of human activity (Riley et al., 2003; Gehrt, 2007; Ticer et al., 1998), likely to avoid contacts with humans. On the other hand, the striped field mouse, which has been strictly nocturnal in rural environments, has become more active during daylight hours in urban areas (Gliwicz et al., 1994).

Diet

A number of species of urban adapted mammals also have been shown to alter their diets in urban environments to consume anthropogenic foods (Ditchkoff et al., 2006). Midsize omnivores appear to be especially adept at utilizing human foods and trash (Fedriani et al., 2001; Prange et al., 2004; Contesse et al., 2004). For example, 14 to 25% of the diet of urbanized coyotes and more than 50% of the stomach contents of urban foxes have been comprised of anthropogenic foods (Fedriani et al., 2001; Contesse et al., 2004). Coyotes have even been shown to feed on house cats. In one study cats appeared in more than 13.6% of coyote's scat (Shargo, 1988). Other shifts in mammals' diets have been observed in urbanized areas. Gray foxes in urban areas consumed more birds and mammals and less plant matter in urban areas, and squirrels have been shown to alter their diet to exploit the exotic plants common in urban environments (Harrison, 1997; Jodice and Humphrey, 1992).

Physiological Differences

Differences in the diets of urban mammals are often cited to explain physiological differences between urban and nonurban mammal populations. Individuals in urban populations have commonly been larger or had a greater body mass than individuals from less developed landscapes (Andrzejewski et al., 1978; Harrison, 1997; Beckmann and Berger, 2003; Harveson et al., 2007). Similarly, body conditions for most urban mammals have been better or equal to nonurban populations (Cypher and Frost, 1999; Grindler and Krausman, 2001), although at exceedingly high densities, body conditions in some urban populations have

shown deterioration (Etter et al., 2002; Hadidian et al., 1987). Urban mammals consuming anthropogenic food also can show differences in weight fluctuations. Urban black bears feeding on garbage gained weight over most the winter, while most bears in nonurban areas hibernate for the season and lose a considerable amount of body weight (Beckmann and Berger, 2003). On the other hand, raccoons that foraged around picnic areas lost more weight than rural raccoons over the winter when the garbage and table scraps were unavailable during the season (Prange et al., 2003).

Some of the most interesting comparisons between urban and rural population of mammals were conducted on striped field mice in Poland. Not only did urban field mice have larger body masses, but they also had different ratios of internal organs to body mass (Gliwicz et al., 1994). Research also found lower levels of white blood cells and a reduced oxygen-carrying capacity in urban striped field, possibly due to the pollutant levels found in an urban setting (Gliwicz et al., 1994). Furthermore, examining morphometrics, researchers found significant differences in skull and bone measurements between urban and rural populations of striped field mice (Gliwicz et al., 1994), possibly indicating the divergent evolution of a population of urban mammal.

Parasites and Disease

The population densities achieved and the clumped nature of urban resources make many urban mammal populations susceptible to disease outbreaks and parasites (Bradley and Altizer, 2007). Disease outbreaks have been shown to be a major cause of mortality in urban adapted mammals such as raccoon (Prange et al., 2003) and red fox (Gosselink et al., 2007). Additionally, the prevalence of disease, such as chronic wasting disease, has appeared to increase with urban development (Farnsworth et al., 2005). Parasites may also be a problem in urban mammal populations. Not only have urban populations of striped field mice shown higher concentrations of ectoparasites, but they have also been found with ectoparasites specific to cats and dogs that have never been found in rural individuals (Gliwicz et al., 1994).

Larger populations of urban adapters are not the only mammals at risk to disease. Rarer species that persist in urban environment can also be susceptible to pathogens from abundant urban adapted species, introduced species and domestic animals. Threatened Allegheny woodrats (*Neotoma magister*) are highly susceptible to the common raccoon parasite *Baylisascaris procyonis*, especially in areas of high raccoon density that can be found around development (Logiudice, 2003). In the United Kingdom, the transfer of paramyxovirus from introduced North American gray squirrels to native red squirrels (*Sciurus vulgaris*) has played a role in the species' decline (Bradley and Altizer, 2007). Moreover, contact with dogs and cats appear to have increased the exposure of urban gray foxes and bobcats to pathogens common in domestic pets (Riley et al., 2004).

The increase of pathogens, metals, nutrients, and novel carbons (Chapter 15, Steele et al., 2010, this volume) along the urban portion of the urban-rural gradient clearly poses a threat to the health of urban mammals. The continued exposure to these pathogens, elements, and compounds is likely to make urban mammals more susceptible to disease, reduce survival, and impair reproduction (Ditchkoff et al., 2006; Bradley and Altizer, 2007). An excellent example of this was found in sea otters (*Enhydra lutris nereis*) off the coast of California. Otters

in areas of high runoff from urban development had infection rates three times higher than otters off the coast of less developed areas (Miller et al., 2002). Urban mammals have also been shown to have increased levels of heavy metals, such as lead (Raymond and Forbes, 1975) and polychlorinated biphenyls (PCBs) (Dip et al., 2003), both believed to have adverse health consequences for individuals. Additionally, exposure of urban bobcats to anticoagulant rodenticides has been strongly linked to mange-associated mortality (Riley et al., 2007).

Use of Anthropogenic Structures in the Environment

The urban environment is dominated by different types of structures, a surprising number of which provide shelter and dens for urban mammals. Small- and medium-sized mammals, such as squirrels, brushtailed possums (*Trichosurus vulpecula*), stone martins (*Martes foinca*), and raccoons, commonly use attics and buildings for shelter and raising young (Adams et al., 2005; Hill et al., 2007). Moreover, urban red foxes, skunks, virginian opossums, Eurasian badgers (*Meles meles*), woodchucks (*Marmota momax*), and armadillos (*Dasypodidae*) make extensive use of the areas under houses for denning (Adams et al., 2005; Harris, 1981; Lariviere et al., 1999; Davison et al., 2008). In some cases urban adapted wildlife almost exclusively use anthropogenic structures for denning. A study of urban stone martins found that 97% of their dens were found in buildings, and inhabited buildings were selected for during winter months, presumable for their warmth (Herr et al., 2009)

Culverts and refuse are two other features of the urban environment commonly used by urban mammals for shelter. Coyotes, foxes, raccoons, skunks (*Mephitis* spp.), black bears, and even spotted hyenas (*Crocuta crocuta*) are just some of the mammals known to use culverts for dens (Barnes and Bray, 1966; Weller and Pelton, 1987; Reese et al., 1992; Adams, 1994; Gosselink et al., 2007; Pokines and Kerbis Peterhans, 2007; Grubbs and Krausman, 2009). Garbage dumps can provide food and shelter for nonnative rats (*Ratus* spp.) and house mice, as well as indigenous chipmunks (*Tamias striatus*) and mice (*Peromyscus* spp.) (Courtney and Fenton, 1976). In Oxford, England, native small mammals used building refuse and garbage for nesting (Dickman, 1987) and North American woodrats (*Neotoma* spp.) have commonly been found nesting in trash and building materials (McCleery et al., 2006b).

Bats as a group are very adept at using anthropogenic structures for roosting and hibernacula. Bats commonly enter houses, roosting in attics and basements (Adams, 1994), and numerous bat species have used bridges and culverts associated with highways for roosting. In fact, 24 of the United States' 45 bat species have been recorded using bridges or culverts as roosts (Keeley and Tuttle, 1999). In Texas, large colonies of Mexican free-tailed bats (*Tadarida braziliensis*) can be found in the center of several cities roosting on building, bridges, and stadiums (Adams et al., 2006; Scales and Wilkins, 2007).

Conservation

Urbanization is possibly the greatest threat to the survival of sensitive and imperiled mammal species (Czech et al., 2000). Most of the mammalian species that occur in or around urban areas are widely distributed, if not ubiquitous species. Nonetheless, there are a few notable exceptions where portions of the developed landscape appear to have benefited mammalian species at risk of extinction. The

Big Cypress fox squirrel (*Sciurus niger avicennia*), listed as a threatened species by the state of Florida, appeared to reach higher densities around golf courses than in natural and protected areas (Jodice and Humphrey, 1992). Golf courses provided the squirrels with a diverse and stable food source (Jodice and Humphrey, 1992). Similarly, conservation efforts in urban areas have become critical to the recovery of the San Joaquin kit fox (*Vulpes macrotis mutica*). Urban kit foxes use golf courses, city parks, and school grounds, and they den in culverts and drainage pipes (Adams et al., 2006). Urban San Joaquin kit foxes likely benefit from their utilization of anthropogenic food, which may explain the increased weight of urban juveniles (Cypher and Frost, 1999). Finally, the federally endangered Florida key deer (*Odocoileus virginiana clavium*), like other white-tailed deer, appear to have benefited from moderate levels of urbanization. Urbanization has resulted in more habitat and food resource available for the deer, in turn leading to increases in the size of the population (Adams et al., 2006). Moreover, urbanization also has increased the weights and survival rates of key deer (Harveson et al., 2007). All three of these species appear to have benefited from the increased resources in areas of moderate development commonly found surrounding the core urban areas. These moderately developed areas with anthropogenic food, high net primary production, and structures for shelter probably hold the most potential for urban conservation efforts directed at populations of native mammals.

Summary

Urbanization continues to threaten mammalian species and alter the distribution of mammalian communities across the globe. Nonetheless, some mammals have been able to cope with the anthropogenic structures, altered vegetative communities, and human activity of urban environments. These urban adapted populations of mammals have been able to utilize the food resource and structures of urban environment and for the most part face a minimal risk of predation. This has helped lead to dense and clumped population of urban mammals, often with increased rates of survival and reproduction. Urban populations commonly differ from nonurban populations in their diet, behavior, physiology, and exposure to disease. It is these urbanized populations of mammals that most of the world's human population will encounter and interact with on a daily basis. The proximity of humans to mammals provides an excellent opportunity for ecological education and research, which are critical for the management and conservation of our planet's mammalian species. It is imperative that we seize the opportunity to further our understanding of how urbanization will continue to alter the composition of mammalian communities, as well the demographics, behaviors, and physiology of mammalian populations.

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