An Overview of the Significance and Management of Vertebrate Pests around Zoological Parks

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ABSTRACT: Zoological parks provide ideal environments for a wide range of vertebrate pests, while at the same time presenting several unique challenges relative to the methods and materials employed for suppressing or eliminating vertebrate pest populations. As a result, zoo park pest management programs must be very carefully designed and implemented. Each of the most significant vertebrate pests requires a species-specific approach within a quality Integrated Pest Management (IPM) framework. Underlying this framework is a necessity for high level cooperation and communication between administrators, veterinarians, individual zookeepers, groundskeepers, pest management personnel and all contracted vendors servicing the park. Because the scope of vertebrate pest management is so broad– especially in the context of a zoo park environment– this paper presents an overview but guides the reader to the appropriate sources of additional pest management information for each particular pest group.

KEY WORDS: bird pests, integrated pest management, rodent pests, urban wildlife, vertebrate pests, zoological parks

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INTRODUCTION

Zoological parks provide ideal environments for a wide range of both invertebrate pests (cockroaches, ants, flies, etc.), and vertebrate pests (e.g., rodents, birds, cats, raccoons, etc.). This is because zoo parks provide pests with 1) habitats protected from predators, and in some areas, climatic threats; 2) abundant and readily available sources of fresh food and water; and 3) diverse and abundant locations providing protective nesting harborages. Consequently, prolific vertebrate pest species such as mice, rats, and sparrows often achieve their maximal reproductive potential inside zoological parks, or at least within some exhibits. Moreover, unless pest populations are eliminated or suppressed below economic and/or aesthetic thresholds, pauses in pest management programs result in rapid population rebounds. Chronic cycles of pest population knockdowns, lulls, rebounds, knockdowns, and so forth are all too common in zoo parks. Lastly, effective long-term pest management inside zoological parks is complicated by the necessary restrictions placed on pesticidal remedies that are typically effective (or at least helpful) in most other urban environments.

The pressures exerted by pests on zoo parks and the accompanying frustrations are fully realized by zoo professionals as well as professional zoological associations such as the American Zoological and Aquarium Association (AZA). In all types of conferences and media interviews, zoo professionals will commonly state "all zoos have problems with rodents and other pests" (e.g., Grimaldi and Barker 2003).

Formal research addressing both insect and vertebrate pest management programs designed specifically for zoological parks is, for the most part, lacking. Pest management is covered in some zoo training manuals and courses (e.g., AZA 2004), and in some pest management textbooks (Bennett et al. 2003, Corrigan 2001, Tucker 1997). Articles and fact sheets regarding vertebrate pest management in zoo parks have occurred periodically– albeit sparsely– within industry trade journals (e.g., Hofmeister 1982; Fotos 1985; Anon. 1991, 1990; Mix 1995) and industry technical symposiums over the past 20 or so years (e.g., Bruesch et al. 1997).

The purpose of this paper is to present an overview of the significance and management of vertebrate pest management programs for zoological parks. Tables 1 and 2 present a listing of those mammals and birds of greatest pest significance to American zoological parks. Other animals (e.g., coyotes, snakes, rabbits, hawks, owls, doves, etc.) may also be pests to zoos depending on a zoo's location and other factors.

ECONOMIC SIGNIFICANCE

The economic significance of vertebrate pests to zoological gardens is five-fold: 1) animal health and welfare, 2) structural damage to exhibits, 3) public health concerns, 4) public relations, and 5) pest management program costs.

Animal Health and Welfare

Of constant concern to zoological park veterinarians is the threat that vertebrate pests harbor, or have the potential to harbor, a range of pathogenic microbes (bacteria, viruses), endoparasites (roundworms, tapeworms), and ectoparasites that may serve as vectors of pathogens (fleas, ticks, lice, mites). Some examples of diseases that can be introduced into zoo parks by vertebrate pests include plague, rabies, listeriosis, leptospirosis, salmonellosis, raccoon roundworm, tularemia, and parvo virus, but there are others (AVMA 2003).

For the commensal rodents specifically, Meehan (1984) lists 11 bacterial, 4 viral, 1 protozoal, 4 helminthic, and possibly 1 fungal pathogen that rats and mice can transmit to livestock, domestic pets, and other animals. The commensal rodents have the potential to serve as exceptional "disease vehicles" due to their biology, body design, and habits around urban buildings (Corrigan 2001). Norway rats for example, may enter zoo parks

Table 1. Mammal vertebrate pests of zoological parks listed in order general significance.

Pest	Pest Significance / Economic Importance	Exhibits / Areas Most Affected	Management Keys
House mouse	*Potential disease vector *Electrical/computer malfunctions from gnawing damage *Electrical/computer malfunctions from gnawing damage	Most areas. Indoor exhibits with warm humid and dark display highly prone to serious infestation levels	*Diligent proactive monitoring *Trapping programs are primary approach. *Rodent proofing buildings and exhibits *Rodenticide baiting applications only in areas where primary or secondary poisoning hazards do not exist.
Roof rats	* Potential disease vector *Electrical/computer malfunctions from gnawing damage * Predator presence stress to some zoo animals	Indoor and outdoor exhibits in regions where roof rats are established. Tropical exhibits especially prone. Attic and wall voids of buildings.	*Diligent proactive monitoring *Trapping programs are primary approach. *Rodent proofing buildings and exhibits *Rodenticide baiting applications only in areas where primary or secondary poisoning hazards do not exist.
Norway rats	*Potential disease vector * Burrowing damage to earthen areas of some exhibits. *Electrical/computer malfunctions from gnawing damage	Earthen areas within or nearby outdoor exhibits especially prone. But commonly infests buildings walls and various structural voids hay storage	*Diligent proactive monitoring *Rodent proofing buildings and exhibits *Snap traps inside trap stations primary approach for infested indoor exhibits *Rodenticide baits via burrow baiting and/or bait stations in areas where primary or secondary poisoning hazards do not exist.
Urban Wildlife: raccoons, tree squirrels, opossums, and skunks	*Potential disease vectors Raccoons nuisance to refuse Raccoons predators on some aviaries	All areas of park. Exhibits along perimeter areas bordered by vegetation or wooded zones especially prone.	Live trapping and removal. Exclusion programs where applicable.
Burrowing rodents: woodchucks, ground squirrels and chipmunks	*Potential disease vectors * Burrowing damage to soil /supporting elements of exhibits and buildings	Earthen areas within or nearby outdoor exhibits.	Live trapping and removal. For some ground squirrel species and locations, possible baiting programs in areas where primary or secondary poisoning hazards do not exist

Table 2. A comparative overview of bird management techniques.*

Method	Target Pest Birds	Product Example	Mode of Action	Management Considerations
Sound noise deterrents	Blackbirds, geese, starlings, gulls,. crows	Pyrotechnics, distress calls, sirens	Sounds frighten birds; disperse them.	May not appropriate for some areas in a zoo park due to stressing or frightening captive exhibit animals. Most effective when used in combination with other methods.
Taste/Gustatory Repellents	Geese	Methyl anthranilate (ReJex-It®, Fog Force®) Anthraquinone (Flight Control®)	Taste repellency and/or intestinal discomfort in geese	Provide fast, but usually temporary results. For turf liquid applications, certain environmental conditions must be met. Mowing and watering practices usually need to be halted temporarily. Weekly treatments may be needed for some flocks. Concentrates relatively expensive and some application operations can be labor intensive.
Tactile/ Adhesive repellents	Pigeons, sparrows starlings, gulls	HotFoot® Roost-No- More® Bird Barrier Gel®	Creates uncomfortable sensation on birds feet or body.	For small areas of surfaces and ledges requiring only temporary results;(e.g., months). Heat, dust and cold can shorten longevity. Staining to building surfaces possible if extreme care not taken in application procedures.
Mechanical repellents	Pigeons, sparrows, gulls starlings, other birds	Nixalite® Bird Coil® Bird Spike® Daddi Long Legs® Bird Blox®	Sharp projections, or wires prevent birds from landing. Some repellents wave and bob to frighten birds.	Installation labor varies from easy to complex and labor-intensive. Some types of prickly wires must be kept clean and maintained. Some newer, inexpensive copolymer barriers "block-out" birds from roosting and nesting on interior ledges and structural framing of garages, sheds, horse stables, barns, etc.
Visual deterrents/ repellents	Blackbirds crows, geese	Balloons w/eyes; fake owls; flashing lights, coyote effigies, dead goose, etc.	Mimic predators; frightens	Not effective against sparrows, pigeons, starlings. Vary in effectiveness to other birds; results temporary unless devices are varied, and periodically moved about.
Lasers	Geese, crows, gulls, sparrows, pigeons*	Avian Dissuader® Desman®	Laser beam frightens, disorients and disperses birds	Easy to learn and use; fast results; effective at night or dark areas. Flock and situation-specific. May require several sessions. Laser equipment relatively expensive
Electrical Bird Deterrents	Pigeons, sparrows, starlings, other birds	Shock Strip® Bird B Gone®	Shocks birds alighting onto strips or charged wires	Labor intensive installation. Regular maintenance and inspections to ensure continual effectiveness. Can provide long term effectiveness properly installed and maintained.
Chase Dogs	Geese	Border collies, Australian cattle dogs, others	Dogs chase/harass and frighten birds	Can be highly effective if conducted properly. May require several sessions to disperse geese for prolonged periods Trainers usually required to manage dogs during chases. Dogs and trainers not readily available in all areas.
Netting	Pigeons, sparrows, starlings, gulls, crows	Stealth Net® Endura Net® Bird Net®	Excludes birds	Requires training, practice and skill for correct installation. Can provide permanent protection properly installed and maintained.
Baits		None recommended for zoo parks		

* adapted from Bennett et al. (2003)

Fecal contamination of any areas that rodents travel is common. The most common rodent pest of zoos, the house mouse (*Mus musculus*), can produce from 40 to 100 fecal pellets ("droppings") and up to several thousand micro-droplets of urine in the course of a single day and night (Bronson 1984). Rats deposit less feces and urine but they have larger volumes of excrement and because of their larger home ranges, they can be spread across more animal exhibits than mice. Rodent-transmitted leptospirosis (rats and tree squirrels) has been periodically responsible for the death of expensive animals in zoos (e.g., Barker and Grimaldi 2003).

Raccoons (*Procyon lotor*) pose significant potential health threats via parasitic, viral, and bacterial pathogens to domestic pets and other animals (Dryden et al. 1995, Martin and Zeider 1992, Snyder et al. 1989, Telford and Forrester 1991). Because raccoons may routinely occupy urban areas encompassing of up to 20 square miles (Kaufmann 1982), and because they possess the dexterity to pry and open many objects, raccoons pose a special health and nuisance threat around zoo parks.

Free-roaming birds also have the potential to adversely affect the health of zoo animals. The primary pest species– pigeons, sparrows, starlings, gulls, and crows– may all inhabit a wide range of unsanitary areas (e.g., city landfills, local restaurant dumpsters, refuse transfer stations, livestock farms, etc.) prior to flying into zoo parks. Similar to mammal pests, birds can harbor and disseminate pathogens via feces or from their mites, fleas, ticks, lice, and/or bird-bug ectoparasites. Urban birds are implicated from time to time in the transmission of fungal, bacterial, viral, and protozoan diseases to humans, pets, and other animals (Chin 2000, Timm and Marsh 1997). Of recent concern is the role of the common, abundant, and prolific urban bird pest species, such as the house sparrow (*Passer domesticus*), in spread of pathogenic viruses such as the West Nile virus and other encephalitides viruses to zoo birds and mammals.

The potential for disease transmission by vertebrate pests to zoo animals is real, but not easily measured. Obviously, zoo parks are apt to respond to any introduced disease issue with a fair degree of confidentiality. As a result, data as to occurrences of pest-related disease events are scarce and spotty, unless deaths occur to high-profile animals and attention is drawn to the event by the local and internet media coverage (e.g., Barker and Grimaldi 2003).

In addition to the potential for disease transmission, the mere presence of some vertebrate pests can negatively affect a captive animal's welfare. Feral cats, raccoons, rodents, and other pests can frighten and stress exhibit animals. When this occurs with expensive exotic animals (i.e., perhaps irreplaceable), the results can be disastrous. In one zoo attempting to successfully breed tree kangaroos (*Dendrolagus lumholtzi*) in captivity (an event difficult in captivity), a single roof rat foraging about at the base of the pregnant kangaroo's roost tree was thought to be causing stress in the kangaroo. Under stress, tree kangaroos are known to discard and abandon their newborn joeys. Unfortunately, the rat was extremely neophobic towards control devices and remained elusive to the zoo staff for several weeks.

In aviaries, raccoons, feral cats, and rats are periodically witnessed by zookeepers and the viewing public chasing down and killing birds as well as eating eggs. These and other vertebrate pests are also occasionally predacious on the eggs and adults of some vulnerable reptiles.

Structural Damage

Gnawing rodent pests periodically inflict serious structural damage to building elements, water lines, feed lines, and sensitive electrical lines of all types that supply environmental controls or display components essential for the visual sophistication of some exhibits.

Burrowing rodent pests such as Norway rats, woodchucks, ground squirrels, and chipmunks can significantly undermine, stress, or collapse slabs, retaining walls, and other supporting elements of exhibits and buildings. The feces from birds are acidic and will stain buildings, statues, and cars. Raccoons tear holes through walls and roofs, as well as damaging all types of elements and utilities via their powerful and highly dexterous front feet.

Public Relations

Most zoo visitors are not concerned when they see an occasional raccoon foraging about the zoo grounds. Nor are they likely to be attuned to what might be an excessive number of tree squirrels, chipmunks, sparrows, or pigeons in a zoo park. Rats or mice foraging about inside exhibits or around the zoo walkways, however, are a different matter. One zoo several years ago had to shut down a pilot nighttime visitation program when visitors began noticing rats readily foraging about on the pedestrian pathways as well as inside several of the popular exhibits. Some visitors unfamiliar with wild rodents thought the rats foraging about near their feet were part of a "live (and perhaps interactive?) exhibit." Although sightings of rats and mice inside zoos by the public is not uncommon, complaints are typically generated only when the rodents are relatively abundant inside cages and exhibits or when they become active in food serving areas or other "people zones".

Many zoos rely on private donations and/or company-sponsored support for programs and animal sponsorships. Patrons visiting zoos are apt to have a poor opinion of their local zoo and the use of their monetary donations upon seeing rats or mice foraging about inside or around sponsored exhibits (e.g., Barker and Grimaldi 2003).

When pests kill exotic zoo animals, or when animals die as a result of a pest management program going awry, negative publicity and embarrassment can occur on a global scale. For example, in 2003 the death of two red pandas bears (given as gifts to the United States) at the National Zoo in Washington D.C. occurred due to a mistake made during attempts to control rats using a burrow fumigant. This event was publicized on radio, TV, most of the major newspapers and across the internet reaching a world-wide audience (e.g., Grimaldi and Barker 2003, Smith and Cohen 2003).

Public Health Threats

In addition to the disease threats vertebrate pests pose to the captive animal population itself, they can potentially harm park visitors (e.g., Gratz 1994). Of course, wild rodents, birds, and other free-roaming animals are not allowed by law to remain active in and around any type of food handling establishment (food processing plants, concession stands, restaurants, school cafeterias, etc.). Sparrows and pigeons foraging on food concession tables inside a zoo also are obviously as unacceptable as if these same areas were used by rats, mice, or cockroaches. Such conditions are unsanitary and pose a potential health threat to people eating on or near feces-contaminated tables and park benches.

Established geese around ponds on zoo grounds may chase and bite children, and a free-roaming cat may bite or scratch an inquisitive child. Such events create just the opposite effect of wanting to bring a child to the zoo to learn to enjoy and appreciate animals; they also invite potential litigation. Feral cats and raccoons roaming the zoo at night may be a potential health threat to visitors from their fleas, or can pose a threat of raccoon roundworm or cat-transmitted congenital toxoplasmosis via the feces from these animals deposited around the grounds or picnic areas (CDC 2004). Finally, many of the vertebrate pests can also add to the disease threat burden placed upon a zoo's general staff that must work on the grounds day-in and day-out.

Pest Management Program Costs

Pest management around zoo parks is a full-time effort. Programs must allow for either full-time staff members to conduct the pest management programs, or have the program contracted out to a qualified firm *experienced* in zoo pest management programs (a point often lost on zoo park purchasing agents). With either approach, the costs of labor and materials needed for daily pest management efforts can be substantial. Annual costs for quality integrated pest management (IPM) programs can easily exceed $100,000 for a city zoo. Without quality programs however, the negative publicity and losses of irreplaceable animals due to diseases, pesticide poisoning, or some other pest-related event can make the costs of IPM programs pale in comparison.

ZOO PARK VERTEBRATE IPM PROGRAMS

Zoological park pest management programs often need to be park-specific and even exhibit-specific within the same park. Pest management programs require constant adjustments and re-evaluations, often with daily study and innovations by persons with intimate knowledge of the park, the exhibit buildings, structures and components, and an understanding of the specific exhibit animals. Moreover, it is essential that a relatively high degree of cooperation and communication be established and maintained among administrators, veterinarians, individual zookeepers, and the pest management personnel. In many ways, managing pests inside zoo parks is similar to pest management in food and pharmaceutical manufacturing plants, child care and health care facilities, animal rearing facilities, and other "sensitive environments" (Tucker 1997, Bennett et al. 2003). To this point, managing pests inside zoo parks must be via the IPM approach. Perhaps the most important tenet of IPM is that pro-active inspections, hygiene, pest exclusion, and non-chemical tools and practices are considered prior to any implementation of pesticides. The specifics of structural IPM programs are often both site- and pest-specific (Grimley and Corrigan 1995).

For the purposes of this paper, zoo park vertebrate IPM programs can be categorized into five broad categories: 1) zoo husbandry practices, 2) pest exclusion programs, 3) general non-chemical tools and strategies, 4) pesticidal tools and strategies, and 5) ongoing monitoring and evaluation programs.

Zoo Husbandry and Park Sanitation

A close adherence to the basic principles of animal care and hygiene as components of animal husbandry throughout the entire zoo park is essential to the general health and maintenance of all the animals; hygiene is the first building block of urban IPM. Several textbooks and courses address the importance of zoo husbandry (e.g., AZA, 2004, Kleiman et al. 1996).

While it may be impossible to remove all food residues within and around all animal displays on a daily basis so as to deny pests food and water, a zoo to a large degree will determine whether a park supports 5, 50, or 500 mice, rats, pigeons, raccoons, or some other pest group at the park via its adherence to sound hygiene programs and practices. For example, the frequent removal of animal waste, clean-up of spilled feed, proper storage of boxes and feed, and other basic zoo husbandry practices will have a important impact on pest management. This point cannot possibly be understated.

The general sanitation of the park itself is also critical in managing vertebrate pests. Whenever possible, food concession and restaurants should not be located nearby highly valued (i.e., exotic) animal exhibits where the food odors and residues will serve to draw rodents, birds, and other pests into these areas. Additionally, all food serving and storage areas must be held to strictest standards of sanitation and storage practices. One unsanitary concession stand can serve as an infestation source for nearby exhibits and offset the gains made in eliminating or suppressing pest populations in the actual exhibit areas.

Similarly, sanitation and storage practices of the zoo's hay barns and feed warehouses are particularly important. Hay bales should be stored away from the walls to allow for inspections and installment of traps, baits, or monitoring devices. This practice facilitates capturing rodents that commonly harbor within hay bales but forage along walls seeking food and water.

In general, IPM programs cannot succeed in zoo parks if there are lapses in basic hygiene at both the individual exhibit and the general park level. And this must be a park philosophy embraced by each park employee and emphasized via a "top-down" path from the park's administration.

Pest Exclusion

For zoo parks, vertebrate pest exclusion programs are situation-specific. Denying larger vertebrate mammal pests entry to buildings and exhibits entails an evaluation of the use of various types of gratings, heavy-duty mesh screens, fences, and so forth. Often, pest-proofing recommendations emphasize rodent proofing of buildings and exhibits. However, much can be done to exclude all pests (insects, birds, urban wildlife, and rodents) as detailed by Scott (1991).

In general, pest exclusion efforts must be done with attention to detail relative to correctly sealing holes, crevices, fascia, door thresholds, utility penetrations, and so forth. Too often maintenance employees (of all commercial structures) equate pest proofing efforts with the simplicity of "weather-proofing" a building, or believe it is acceptable to "quick plug" obvious mouse holes using wads of copper or steel wool. Or, "caulks" and "expanding foams" are used instead of surface-specific sealants to properly close off crevices and gaps pests use to gain entry (Corrigan 2001). Unfortunately, incorrect pest exclusion efforts can often exacerbate pest entry and harborage issues. Wherever possible, enclosed hollow spaces in walls, floors, ceilings, and so forth should be avoided to deny roof rats, house mice, and other vertebrate pests such ideal harborages. If structural elements cannot be made solid, extra efforts should be made to ensure the elements are totally enclosed and rodent-proofed with metal flashing or with the proper sealants at the appropriate seams.

Considering the pest challenges zoos face, pest exclusion programs should be pro-active. Maintenance personnel should schedule preventative maintenance inspections of doors, roof fascia boards, cement slabs, roof areas, screens, vents and louvers, and so forth. Well-designed preventive maintenance programs are usually conducted on a quarterly basis, or at least quarterly on those buildings or parts of a building or exhibits subjected to intensive use by animals, staff, and visitors. Several excellent references are available on pest exclusion that can provide zoo maintenance staff with guidance (e.g., Scott and Borom 1965, Jenson 1979, Scott 1991, Baker et al. 1994, Corrigan 2001).

General Non-Chemical Recommendations

In addition to good animal husbandry and pest exclusion programs, a wide range of non-chemical tools and strategies can have significant impact on suppressing vertebrate pest populations in zoo parks. The following non-chemical recommendations for zoo parks are compiled from Hofmeister 1982, Fotos 1985, Anon. 1991, Tucker 1997, Corrigan 2001, and Bennett et al. 2003:

- Landscaping programs around the exterior areas of exhibits and park buildings should be carefully considered. For example, shrubs that form cavernous shapes and are closed at their bases or form carpet-style shrubs that splay over the ground should be avoided. These include shrubs and bushes such as yew bushes, creeping junipers, arbor-vitae, and ivys. These types of plants provide good harborage for rodents, birds, and urban wildlife. Such plants also trap trash and food scraps, which in turn contribute towards pest problems. Depending on the number of shrubs and their location, such plantings can also serve as peripheral nesting reservoirs in which pests can regularly disperse to nearby animal exhibits.
- Tree and shrub branches should be cut back by at least 2 m from buildings and exhibits to help reduce squirrels, mice and rats, and other pests from developing easy and perhaps secretive entry areas to buildings and exhibits.
- In areas where ivy is particularly desirable, Algerian ivy (*Hedera canariensis*), can be kept to a 30-cm height without loss in aesthetics, which eliminates the dense understory cavernous habitat that rats love.
- For zoo parks with palm trees, dead palm fronds should be eliminated and the trees kept tidy to prevent roof rats from nesting within and beneath layers of dead fronds.
- Around the immediate foundations of buildings and exhibit cages, bare strips of gravel, crushed stone, or concrete should be maintained. This practice significantly reduces the possibility of Norway rats and other burrowing mammal pests from establishing burrows in these areas. However, for safety reasons, any stones or pebbles that are throwable will need to be avoided around certain exhibits.
- The management of all food refuse at the park should be a well-structured program. For example, refuse dumpsters used at a zoo park should be carefully selected for appropriate models, placement, proximity to sensitive buildings, cleaning, pick up frequency and timing, and other issues. Food refuse should never remain in exterior dumpsters overnight. Otherwise, refuse containers near buildings and general areas will serve as "pest magnets" for rodents, birds, and urban wildlife (as well as ants, stinging insects, etc.). Zoo parks with heavy bird and/or urban wildlife pressures should consider having food refuse dumpsters removed from vulnerable exhibit areas and possibly the entire grounds several times each day.
- All incoming supplies of animal feed, bedding, bird seed, or other items subject to pest infestations should be carefully inspected prior to acceptance by the zoo staff. Because some items may not subject to the same rigorous food safety demands (i.e., FDA and USDA) placed on human food during production, transfer, and storage, they are sometimes prone to pest infestations. Without good inspection programs, pallets with these materials can sometimes serve as "pest Trojan Horses" to zoo parks. Any arriving products that contain pests should be rejected and records kept as to the incident for future reference. Certain vendors may in fact be in need of better pest management programs themselves, and if not monitored, may send pests on a periodic basis.
- Whenever possible, zoo animals' foods should be removed when captive animal feeding is done– at least during times when pest infestations are being battled. If foods are allowed to remain, they will feed rodents as well as insect pests (cockroaches, ants).

Pesticidal Tools and Strategies

For obvious reasons, all pesticidal and lethal approaches for managing vertebrate pests in and around zoo parks need to be carefully planned, using a good deal of forethought. Around animal exhibits, there is no room for mistakes with pesticides or lethal approaches (e.g., Barker and Grimaldi 2003). Thus, in most cases, pesticides are the least desirable component of a pest management program– although occasionally they may be necessary under carefully controlled conditions.

Unfortunately, there is also a fair amount of misunderstanding among park personnel regarding the use of pesticides, repellents, and even non-chemical means of vertebrate pest management. Some zookeepers maintain an adamant position of "no pesticide applications" for the exhibits for which they are responsible. But while safety is "priority one" when pesticides are being considered, an complete ban on all pesticides can be short-sighted and lead to the inefficient and costly harvesting of pest populations instead of population elimination– at least at a specific exhibit level. Such attitudes can also ignore how highly effective low-hazard pesticide programs can be when employed by skilled and experienced pest management professionals.

Ongoing Monitoring and Evaluation Programs

To maintain the success and progress of zoo park IPM programs, ongoing monitoring and evaluation programs are essential. Pest sighting logs and activity maps should be maintained by zookeepers and other zoo staff for cafeterias, feed storage buildings, etc. Using the data collected from new sightings of pests and pest signs (e.g., rodent excrement), evening inspections, trapping, and bait station activity, pro-active strategic programs can be routinely employed that can stem off potentially serious infestations. Ongoing monitoring programs also allow for strategic planning to pro-actively "surround" those buildings, exhibits, and areas showing pest activity, thus working inward towards eliminating source populations. Such programs are particularly important for commensal rodent IPM efforts.

PEST-SPECIFIC IPM PROGRAMS

Commensal Rodents

Among the vertebrate pests of zoo parks, the commensal rodents (the house mouse, the Norway rat, *Rattus norvegicus*, and in some areas, the roof rat, *R. rattus*), are by far the most significant pests. A discussion of rodent biology and behavior is easily obtained via a body of literature on commensal rodents (e.g., Jackson 1982, Prakash 1988, Smith and Buckle 1994, Hygnstrom et al. 1994, Frantz and Davis 1991, Corrigan 2001). The following are some practical recommendations for the management of rodent pests in zoos parks based on efforts of industry pest professionals (Hofmeister 1982, Fotos 1985, Bruesch et al. 1997, Corrigan 2001) or on the author's work as a rodent control consultant serving sensitive environments.

Pro-Active Rodent Inspections and Monitoring

Because of the propensity of zoo parks to contain chronic infestations of rodents, pro-active inspections and monitoring should be considered by zoo staff members and by contracted pest professionals as equal in importance in the overall rodent management program to the use of traps, baits, bait stations, and so forth. Ongoing inspections should be targeted to those buildings and exhibits with previous infestations; rodents often re-infest the same buildings, and indeed the same building spaces repeatedly, due to their attractive environs and availability of resources.

Because rodents are generally nocturnal in their behavior, evening inspections beginning about 60-90 minutes after dusk is often a time window that reveals the presence or absence of rodents, their high activity zones, and areas of chronic infestations. These inspections should be done quietly and unobtrusively. Night vision binoculars, which can dramatically aid in evening inspections for rodents and other vertebrate pests, are now available at a reasonable cost.

Some pest professionals and zoo staff pest specialists maintain monitoring bait stations containing non-toxic baits (e.g., Detex®) in rodent-vulnerable areas and exhibits. Should the monitoring stations show activity, rodenticide baits or trapping programs can then be initiated in active areas.

Additional information on pro-active inspections and monitoring programs is available in the literature (e.g., Marsh and Howard 1977, Pratt and Brown 1982, Marsh and Baker 1986, Frantz and Davis 1991, Corrigan 1996).

Interior Mouse Infestations

With a few exceptions, the house mouse tends to be a universal pest of zoos. It is not uncommon for it to be present in every building and every exhibit in a zoo park. The reasons for this are the mouse's small size, adaptability, small home range, ability to thrive on tiny amounts of food and water, and high reproductive potential under good conditions. Berry (1981) refers to the house mouse as a "mammalian weed".

Because many of the newer, progressive indoor exhibits can be very sophisticated structures with hundreds of nooks and crannies and contain environmental conditions for maximal health to zoo animals, the house mouse usually thrives in these environments. Consequently, among the three commensal rodents, mouse management efforts in a zoo often demand the most intensive labor and time commitments.

Norway Rat Infestations

Around zoo parks, Norway rats are usually the most problematic where these rodents can burrow in areas that allow for earthen harborages and within relatively close proximity to a dependable food source. Occasionally however, they will also harbor within various types of wall, floor, and ceiling voids, structural conditions permitting.

Roof Rat Infestations

In those parts of the world where roof rats occur, this rodent can be especially troublesome in zoo parks. This is because the roof rat tends to be elusive and more independent of humans and human food than does the Norway rat. Part of the roof rat's elusiveness is its nature to harbor in attic, ceilings, walls, soffits, and among the natural nooks and crannies of trees and dense vegetation. These types of areas are out of the normal perspective of most people.

Also, the roof rat can exist feeding on various invertebrates such as large cockroaches, slugs, and snails, and on fruits, berries, and nuts. These foods, in and around zoo exhibits that contain lush vegetation, are often independent of either human food or zoo animal feed. Marsh and Baker (1987) provide excellent insight into the behavior (and control) of roof rats.

Rodent Management Recommendations

Trapping Programs

For routine, ongoing maintenance programs of minor but chronic rodent infestations, the use of snap traps and/or multiple-catch traps (for mice) can provide effective rodent control. The following suggestions are provided:

- Over the past several years, new innovations have been made in both mouse and rat traps models. Plastic models are available that provide long-term durability, ease of use, and bait trigger designs that minimize trap escapes.
- Snap traps can be installed within most of the commercially available tamper-resistant bait stations rendering them "trap stations". In most instances, trap stations will protect non-target animals from being harmed or frightened by the snap traps. Trap stations also keep the traps out of public view.
- Multiple-catch mouse traps can be effective in areas and rooms that do not contain much clutter, as mice explore these traps based upon an opportunistic response for harborage. In areas or exhibits containing lots of nooks and crannies, or abundant clutter, snap trap stations may be a better choice of trap.
- Trap stations can be kept in perimeter zones of previously infested cages to stem off any new, incoming rodents. Such stations are also good preventative-maintenance bait stations around water sources and ponds, where rats tend to establish chronic infestations.
- For rat trapping programs, traps should be pre-baited for 1 - 3 days prior to being set, to help acclimate and condition a local rat colony towards the traps and thus to maximize trap captures once the trapping program begins. The consequence of not pre-baiting snap traps can be significant, resulting in "trap shy" or "smart" rats, which can become especially difficult to control thereafter. A list of strategies for dealing with trap shy or neophobic rats for zoos and other situations are discussed by Corrigan (1997, 2001).
- In general, rats and mice do not have "favorite" food baits. In many cases, matching the foods upon which the rodents are already feeding makes for good trap baits. These baits can be supplemental with novel baits that may entice some individuals. For example, mice often respond well to chocolate syrup squeezed onto triggers as well as the use of bacon-bits, oatmeal, peanut butter, and so forth.
- Norway rats may respond to food groups opposite those they obtain during daily foraging. Meat baits may entice rats if their normal foods are grains or seeds, and vice versa.
- The natural foods of roof rats, such as fruits, nuts, insects, slugs, and snails, often serve as good baits for this species. In fact, for this rat, natural food baits may be preferred over processed human food baits– especially by neophobic or cautious roof rats. Thus, tying snails and/or snail shells (using strips of dental floss) to a trap may attract even the most shy roof rat.
- Pest professionals for many years have reported that the live, "humane" traps used for urban wildlife species (e.g., tree squirrels, chipmunks, raccoons, etc.), tend not to be effective against the commensal rats– probably due to rats' cautious behaviors towards such devices. For roof rats, effective nest-box live traps can be improvised using ordinary empty tamper-resistant bait stations installed into roof rat-active areas (Corrigan 2003 a,b).

Rodenticide Baiting Programs

Rodenticide baits can play a critical and sometimes irreplaceable role in zoo park rodent control. Certainly, extra caution must be exercised for every situation in which baits are considered– even when quality tamper-resistant stations and techniques are employed. Nevertheless, rodenticides can be used quite safely in zoos.

- Due to the high value of many zoo animals and their extreme sensitivity to many pesticides, the use of any vertebrate pesticide must be very carefully undertaken. Park veterinarians must know at all times which rodenticides are being used and where. Vets should be provided or obtain all current up-to-date MSDS sheets, labels, and toxicological information regarding any rodenticides used at a zoo.
- Staff veterinarians must fully understand and be able to recognize symptoms of rodenticide poisonings, as well as knowing the necessary antidotal treatments, should any be needed (Battan 1985, Murphey and Gerkin 1986, Pelfrane 2001). In most cases, the pesticide manufacturer should be considered as the best source of information for questions regarding the use and/or toxicity of any pesticide (Bennett et al. 2003).
- Rodenticides, for example, vary widely in their toxicity levels to different zoo animals among birds, mammals, reptiles, fish, and amphibians. Among the anticoagulant rodenticides, the active ingredient should be selected carefully to maximize employing the rodenticides with the lowest toxicity potential to the different zoological animals. For example, cholecalciferol is often the bait of choice in aviaries due to its low toxicity to birds, but it is of concern around canines and felines (Gunther et al. 1988, Moore et al. 1988). Various publications are available to help veterinarians and pest professionals compare toxicity ratings among the conven-

tional rodenticides (e.g., Hone and Mulligan 1982; Battan 1985; Godfrey 1985; Marsh 1985a,b; Lund 1988; Kaukeinen 1993; WHO 1995; Pelfrane 2001).

- When rodenticide baits must be used inside buildings or within the proximity of animal exhibits, tamper-resistant bait stations should always be used. A wide variety of commercial stations that are species-specific (mice, Norway rats, roof rats) are available for targeted baiting.
- Some zoos improvise with different combinations of bait stations concealed beneath secured, heavy-duty utility boxes that are used to house in-ground irrigation systems, electrical circuitry, and other applications– in other words, bait station-within-bait station protection.
- The choice of a rodenticide formulation (i.e., pellets, packets, meal, block, liquids, and tracking powders) must be carefully determined according to the targeted use. Only those rodenticide formulations that minimize the chances of translocation and spillage for the specific intended use should be considered. For example, for bait station baiting programs, only block formulations should be used, because the blocks can be secured within the stations. Loose pellets and packets cannot be secured and thus are prone to be carried out of the stations by rodents. Also, block baits are not prone to being ingested by birds. Block baits are also best suited for tropical environments of high humidity and warm temperatures.
- For direct burrow baiting of Norway rats, however, loose pellets applied deeply into burrows that are then left undisturbed, minimize the chances of the bait being rejected back onto the surface, as compared to block and packet-style baits.
- In general, baits should never be installed into exhibits of captive animals that may be capable of intentionally or accidentally destroying tamper-resistant bait stations. If baits must be used in these exhibits, animals should be temporarily relocated for the baiting period and the baits removed following treatments.
- Some zoos construct "artificial rocks" of varying sizes from cement and fiberglass within which bait stations can installed. Rock-camouflaged tamper-resistant bait stations are now available from several manufacturers.

Secondary Poisoning Concerns

Secondary poisoning risks should be kept in mind at all times when rodenticides are being considered for zoo parks. From a practical aspect, small dosages of a rodenticide ingested by most zoo animals only once or twice are not likely to result in the death of the animal. But secondary transfer of a rodenticide is possible if the active ingredient is passed unchanged through the rodent's digestive system and into the fecal pellets, which could become toxic if ingested by birds, reptiles, small mammals, or perhaps by some hypersensitive animal. Captive animals may, out of boredom, ingest contaminated feces or insects (e.g., cockroaches, ants) that have fed on a grain-based rodenticide. If this occurs on a periodical basis, small amounts may culminate in a toxic dose.

The concern also exists that poisoned, near-death rodents will be eaten or partially eaten by zoo animals. Over the years, birds, squirrels, and other non-target animals that were not known to have any direct access to rodent baits have been found via autopsies to be poisoned by rodenticides.

Concerns with secondary poisoning risks highlight the importance of a pro-active program that emphasizes monitoring. By doing so, newly established infestations can be halted early on using non-chemical tools and techniques and thus minimizing the need to introduce rodenticides into an area.

Urban Wildlife

Depending on the geographic location of the park, various wild animals can become pests in and around zoo parks. However, raccoons, skunks, tree squirrels, and ground squirrels make up the most commonly encountered urban wildlife pests in zoos. Each of these pests may require species-specific management programs. For detailed programs on any particular urban wildlife pests, the reader is referred to the well-known reference manual *Prevention and Control of Wildlife Damage* (Hygnstrom et al. 1994). This manual can also be accessed via the web (www.wildlifedamage.unl.edu)

In addition to the IPM approaches of hygiene and exclusion programs, the primary urban wildlife pests inside zoos are usually managed via live-trapping and removal programs. Depending on the specific pest, the offending wild animal may be relocated back outside the park to an area where it will not cause any harm or damage to anyone else's property. Or, the offending animal is euthanized at the zoo park by the staff veterinarians. In some states, animals such as raccoons, skunks, and feral cats are required by state law to be euthanized to minimize the threat of spreading rabies and/or other diseases.

Even if zoo parks contract their general pest management programs for rodent and insect pests, many conduct their own wildlife trapping programs because of their in-house familiarity and expertise in capturing and handling animals. Thus, a detailed discussion on the techniques and materials needed for live trapping is not necessary here. Many zoo park personnel are quite experienced in this regard. Additional information on urban wildlife management, live trapping strategies, etc., is available from Timm and Marsh (1997), Bennett et al. (2003), Wegner (2003), and by accessing the wildlife damage control website listed above.

For situations where live traps are ineffective (due to trap-shy animals) or inappropriate, carefully planned sharp-shooting sessions during shutdown hours can be employed for some wild animals, birds, and rats.

Bird Pests

The common house sparrow and the feral pigeon (*Columba livia*) comprise the two most common pests of most zoo parks. However, the house finch (*Carpodacus mexicanus*) has become as, or more, numerous as the house sparrow in some areas. Zoo parks located near

seashores and major waterways are also subject to significant gull and/or Canada goose infestations. Crows, ravens, purple finches, black birds, doves, hawks, and a variety of other bird species may also be chronic or periodic pests at some zoos, depending on the zoo's locale.

In some ways, bird pest infestations and issues around zoo parks are the most challenging of all the vertebrate pests. This is because of the variety of pest species, each having specific feeding, roosting, and nesting behaviors. Additionally, few options other than bird exclusion, mechanical repellents, and harassment campaigns exist for managing bird pests around zoos. And finally, all birds with the exception of the house sparrow, pigeon, and starling are offered protection by federal law. In some areas, local ordinances may protect all birds or at least restrict the options available for their management. Consequently, managing bird pests around zoos is often species and location specific.

Similar to rodent and urban wildlife pests, a strong IPM program is essential for zoo park bird management programs. An overview of bird management techniques and materials by bird pest group is provided in Table 2.

Sanitation is difficult to attain to a level that will dramatically impact urban bird pests, because park visitors drop food items along walkways and picnic areas throughout a zoo park, virtually ensuring that the free-roaming birds have access to food all day long. Moreover, many visitors perceive feeding the pigeons and other birds as part of a day at the zoo. To offset this impact requires unrelenting cleaning efforts by zoo staff several times a day. But rarely do budgets permit such operations. At the very least, strict sanitation efforts around food stands, food refuse containers, and dumpsters that are in close proximity to exotic animal or highly sensitive animal exhibit areas, must be considered top priority.

Where not prohibited by local or federal laws, nest removal campaigns as a component of exterior sanitation can result in long term suppression, and even elimination, of house sparrow and house finch populations– at least in localized areas and around certain exhibits. This is because these small birds have limited home ranges (1 - 2 square miles) and relatively high natural mortality rates (40 - 60% annually), depending on the severity of the winter months (Fitzwater 1994). Thus, regular removal of all sparrow nests on buildings, signs, atrium utilities, and so forth can significantly impact sparrow population in just a year or two. Sparrow nests and eggs should be located and removed at 10- to 14-day intervals– especially during the spring season. Nests can be removed using long poles with hooks attached to the ends. The nests and all nesting materials should be discarded to force the female sparrows to "start from scratch" in rebuilding the nest. The females often attempt to rebuild the nest a few times after the original nest has been removed, but after several unsuccessful attempts, they usually vacate the building site and often the general area.

Pest exclusion programs for birds involve carefully planned efforts considering a wide range of technology. Scott (1991) provides an excellent discussion on bird (and other pests) exclusion principles relative to the buildings themselves.

To supplement general pest proofing programs, bird netting, ledge-denial mechanical devices (e.g., Martin and Martin 1982), and a wide range of new bird control technology can be employed. It must be stressed however, that bird exclusion programs are detail-specific operations, usually requiring professionals who specialize in industrial bird management. If this work is performed by well-intentioned but inexperienced persons, it often exacerbates the problem with costly consequences.

Certain bird pests (e.g., geese and starling flocks) can be harassed on a routine basis via trained dogs, laser guns, pyrotechnics, water jets, distress calls, and other means (Cleary 1994, Solman 1994, Dolbeer et al. 1998, Gingrich and Osterburg 2003). Here too, specialists trained and experienced in the use of such tools and techniques are necessary. Recent technology involving the use of laser guns may hold promise for managing gulls, geese, starlings, and other bird pests at zoo parks, or at least for keeping these birds from roosting and nesting in the more sensitive sections of the zoo park (ANSI 1999, Glahn and Blackwell 2000, Blackwell et al. 2002, NPMA 2003).

For detailed management programs on specific bird pests and/or updates in bird management technology, the reader is referred to the pertinent references listed at the end of this paper (e.g., Hygnstrom et al. 1994, Timm and Marsh 1997, Smith et al. 1999, Kramer 2001, Bennett et al. 2003, Wegner 2003, or visit www.wildlifedamage.unl.edu).

SUMMARY

Zoological parks are intrinsically vulnerable to vertebrate pest issues and pest infestations. Consequently, pest management efforts must be unrelenting and progressive, employing the IPM approach. Virtually any wild mammal, bird, reptile, and even amphibians, may pose pest problems at a particular zoo. Thus, managing a pest beyond those discussed here, or in greater detail than that discussed in this paper, requires a careful review of the five steps of vertebrate IPM coupled with a pest-specific management strategy, as available in the literature.

Finally, it must be emphasized that progressive pest management programs in zoo parks requires a highly cooperative involvement of all staff, involving park administration, staff veterinarians, zookeepers, grounds maintenance personnel, food-service employees, and all contracted companies working or serving the zoo (e.g., pest control companies, food supply vendors, refuse container companies, etc.).

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