Citywide biological monitoring as a tool for ecology and conservation in urban landscapes: the case of the Tucson Bird Count

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Abstract

As urban areas worldwide continue to grow, the cities in which we live, work, and play can take on an increasingly vital role in sustaining biological diversity. Studies of bird communities in metropolitan areas show that our cities generally remain places inhospitable to most native bird species. However, gaps exist in our understanding of the principles needed to design metropolitan landscapes that better sustain native birds. Long-term data collected of a range of spatial scales across a city can aid in filling these gaps. To evaluate an approach to collecting such data, and to address unanswered questions concerning birds in populated areas, I organized a volunteer-based bird monitoring project (the Tucson Bird Count, or TBC) in Tucson, Arizona, USA. In the TBC, skilled observers surveyed the breeding bird community at hundreds of sites throughout Tucson. This paper reports results after the second year of this ongoing project, and has four objectives. First, it discusses issues of survey design in relation to scientific and conservation data needs. Second, it tests the ability of a citywide survey to rapidly prioritize species according to their sensitivity to development. Third, it presents a novel approach for quantifying the impact to humans of reduced diversity in urban areas. Finally, it concludes with an evaluation of the viability of volunteer-based, citywide surveys as tools for research and monitoring in cities in general, citing specific examples from this Tucson study. Volunteer-based, citywide surveys offer high-visibility, efficient means to acquire data unobtainable by other methods, presenting great potential to advance ecology and conservation.

Keywords: birds; urban wildlife; conservation; monitoring; Tucson Bird Count

Introduction

Human-dominated landscapes occupy a large and increasing proportion of the Earth's land area (Vitousek et al., 1997), and harbor a substantial portion of global biological diversity (Pimentel et al., 1992). Urban areas are of particular concern: many cities are growing rapidly both in area and in population. The proportion of all humans living in urban areas will soon surpass 50 percent worldwide (80 percent in more developed regions), and is expected to continue rising for several decades (United Nations Population Division, 2001). Accordingly, the areas in which we live, work, and play, if managed appropriately, can play an increasingly vital role in sustaining the world's species (Rosenzweig, 2003). Moving toward uses of urban and suburban land that help sustain native plant and animal populations can aid in conserving biodiversity by increasing the habitat area available to living things (Rosenzweig, 2003). In a world made up increasingly of city dwellers, it may also give humans more contact with nature, potentially improving quality of life (Shaw et al., 1985; Clergeau et al., 2001) and increasing human appreciation of nature in general (Schicker, 1986; Rohde and Kendle, 1995).

While admittedly not the only taxon present in urban areas, birds as a group are often common denizens of these environments. Their conspicuous visual presence and vocal habits render them relatively easy to study (Konishi et al., 1989), and they have been proposed as indicator taxa for species less easily observed in inhabited areas (Blair et al., 1999). Studies to date generally show depressed abundance and diversity of native bird species in urban areas, with increased abundance only for a few synanthropic exotic or native species (e.g., Emlen, 1974; Clergeau et al., 1998). But must humans harm nature with their mere presence? Studies surveying multiple sites within urban areas (e.g., Mills et al., 1989) demonstrate variation in the capacity of different developed sites to support bird populations. This suggests that we have the opportunity to design urban landscapes better able to sustain birds than those we live in now. A long-term goal of urban ecologists, then, should be to uncover the factors regulating the success or failure of species in inhabited areas, and use these factors to develop principles for the design of urban landscapes compatible with nature.

But the attainment of this goal has been hampered, in part, by a lack of adequate data. Particularly lacking are data (1) collected over the multiple spatial scales relevant to urban ecological processes; (2) spanning the variety of land uses present in developed and nearby areas; or (3) repeating surveys at the same sites on a long-term basis. To evaluate an approach to collecting such data, and to address unanswered questions concerning birds in populated areas, I organized a volunteer-based bird monitoring project (the Tucson Bird Count, or TBC) in Tucson, Arizona, USA. This project has now operated for two years and will continue annually, allowing additional research questions to be addressed as data are accumulated over time, and as supplemental data sets (e.g., high-resolution land cover maps) are completed. For now, the current paper presents initial results of the Tucson Bird Count's efforts, and has four specific objectives. The first is to discuss issues of survey design in relation to scientific and conservation data needs. The second goal is to test the ability of a citywide survey to rapidly prioritize species according to their sensitivity to development. The third is to use a novel approach to quantify the impact to humans of reduced diversity in urban areas. A final objective is to evaluate the viability of volunteer-based, annual, citywide surveys as tools for research and monitoring in cities in general, citing specific examples from this Tucson study.

Methods

Survey design

The general strategy of the Tucson Bird Count is twofold. First, the TBC seeks to pool resources, enabling the collection of data not available in smaller studies and, thus, allowing previously unaddressable questions to be addressed. Second, the TBC seeks to maximize the applicability of data collected to urban science and conservation efforts. Of course, no single survey can provide all data necessary for every research question. However, a well-planned effort can furnish data for a number of studies, provide a framework upon which more detailed investigations may be organized, and suggest what those investigations ought to be.

Several study design factors emerge which may improve the usefulness of a biological survey to a variety of urban ecology questions. First, the survey should encompass a range of spatial scales (i.e. various lag distances among survey points) so as to facilitate investigations of the scaling relationships between birds and the urban environment. For example, knowing the spatial scales at which birds respond to landscape structure (e.g., Hostetler and Holling, 2000) can guide the design of networks of suitably sized and spaced habitat patches throughout cities. Second, the survey should cover as many variations in land use as possible. Biologists generally lack the resources to conduct experimental manipulations on the scale of metropolitan areas, so we must take advantage of the many ‘natural experiments’ (*sensu* Diamond, 1986) conducted in the development of cities. As a final general principle, the survey must be efficient, in terms of both monetary cost and time spent by participants. An efficient survey design is more likely to be repeated at the same site in future. Longitudinal study is critical, as the study of urban ecology is – for the foreseeable future at least – a study of change. Moreover, efforts to restore native species in populated areas will benefit from an adaptive management approach (Holling, 1978), in which a monitoring program provides continual feedback (in this case, at the local, neighborhood, or citywide scale) on the responses of species to land use changes and management actions. An efficient survey design is also more likely to be attempted in other urban areas. Data from additional cities can alleviate problems of pseudoreplication present in some landscape-level analyses (Hargrove and Pickering, 1992). In addition, although some general principles have emerged from the study of wildlife in urban areas, not all areas, human cultures, and natural communities are the same. Thus an efficient protocol that can be implemented in different areas should be developed.

The North American Breeding Bird Survey (BBS; Sauer et al. 2001) implements all of the above factors, with a few exceptions: (1) the BBS surveys at the scale of a continent rather than a metropolitan area; (2) the BBS deliberately avoids urban areas in route placement, and moves routes away from cities when development encroaches (O’Connor et al. 2000). The BBS has been efficient and remarkably successful in its use to science and conservation (O’Connor et al., 2000). The approach chosen for the Tucson Bird Count is based on the BBS, with both the total extent and spacing of survey sites reduced. The stratified random approach, in which one survey location is placed randomly within each cell of a regular grid, provides distributional information seldom collected at the scale of an urban area (see Hadidan et al., 1997 for one exception). Increasing the number of sites surveyed is generally preferable to repeated visits if travel between sites is efficient (Link et al., 1994). Since travel time is a small cost in urban areas, additional effort was spent on additional sites rather than repeated visits. Also like the BBS, the TBC is a volunteer-based survey, deriving its economy from the modest individual commitments of a large contingent of amateur and professional birders.

Study area

The Tucson metropolitan area comprises roughly 1300 km^2 in southern Arizona, USA at around 780 m elevation. The area’s human population has increased rapidly in recent years, with that of Tucson proper increasing 20.1% from 1990-2000 (United States Census Bureau, 2000). Over 800,000 people now inhabit the metropolitan area. Outward development continues in all directions not constrained by government-owned lands.

Original habitats immediately surrounding Tucson are predominately upland Sonoran desertscrub (Brown and Lowe, 1980), comprising various trees (*Cercidium* spp., many of which exhibit shrub-like growth), shrubs (e.g., *Larrea tridentata*, *Encelia farinosa*), a columnar cactus species (*Carnegiea gigantea*, the giant saguaro), and other cacti (*Ferocactus wislizenii*, ten or more *Opuntia* spp.). Small amounts of mesquite woodland and forest remain in the study area (*Prosopis* spp.), primarily to the northeast. Desert vegetation has been thinned substantially in suburban areas, and in urban Tucson, it is structurally different where it does occur. Non-native ornamental plantings and shade trees (*Eucalyptus* spp., *Pinus halepensis*, etc.) predominate in developed areas, with planted trees spaced among parcels such that urban Tucson structurally more closely resembles savannah than the desertscrub or woodland vegetation types once common here. Surface water is available perennially at very few locations; most washes flow only after heavy rain, although one section of the Santa Cruz River flows with treated effluent.

The initial Tucson Bird Count study area encompasses 730 km^2 of land in and around metropolitan Tucson, AZ (Figure 1). I selected this study area to include areas of rapid development and gradients in vegetation and land use. The study area extends roughly between the large parks to the west (Tucson Mountain County Park and Saguaro National Park West in the Tucson Mountains) and east (Saguaro National Park East and the Coronado National Forest) of Tucson, to 1000 m elevation in the Santa Catalina Mountains (Coronado National Forest) to the north, and to the San Xavier Indian Reservation to the south. Within 30 km of Tucson's city center, elevation varies from 670 m to the northwest, to 2791 m atop Mt. Lemmon to the north. However, the TBC's interest is in bird species actually or potentially using land within inhabited areas in and near Tucson. Thus, the TBC excludes areas above those elevations at which development generally takes place (about 1000 m).

Using a Geographic Information System (GIS), I divided a map of the study area into a grid of 1 km^2 cells, and selected a random point within each cell as a survey site. Point placement was done independently of the presence of roads or other features. I avoided a fixed array of points (e.g., grid vertices) because many Tucson roads (and thus parks, etc.) are aligned directly north-south or east-west, and could produce spurious correlations if such a design were used. I chose the cell size of 1 km^2 based on the coverage desired and estimated observer effort available.

I grouped nearby sites into 'routes' which could be easily traversed by one person with a car or bicycle in a single morning. To reduce spatial autocorrelation among sites for a given observer, I made routes as near linear as practical. The resulting 71 routes contained sites from 8 to 12 contiguous grid cells apiece, with those in less accessible areas having fewer sites. I created two additional routes for areas less accessible by public roads: Davis-Monthan Air Force Base (entirely within Tucson, 43 sites) and Sabino Canyon Recreation Area (Coronado National Forest, 9 sites). Additionally, I coordinated monitoring protocols with Saguaro National Park's Inventory and Monitoring Program so that data could be exchanged between the two programs. This added 9 sites in Saguaro National Park West and 4 in Saguaro National Park East. These 13 sites were not contiguous with each other or with the other sites, but otherwise followed the same protocol as all other sites (located randomly, etc.).

Survey period

Dates when Tucson-area birds are most detectable vary among species, due to differences in timing of reproduction, migration, and other factors. Thus, I consulted a number of local ornithologists to select a survey period – 15 Apr to 15 May – when the greatest number of bird species are vocalizing consistently. This one-month survey period accommodates observers' schedules and allows multiple routes per observer, increasing the total effort available.

Observers and survey management

I recruited skilled observers through the Tucson Audubon Society newsletter, a regional birding e-mail listserv, and personal communication (for this study, a "skilled observer" is defined as one who can identify the 25 most common Tucson-area species quickly by sight or sound, is familiar with most other birds of the Tucson area, and may need quick reference to a field guide for certain less-common or difficult-to-separate species). Observers used the TBC web page to view a survey area map, register, and adopt routes. Each observer received a detailed roadmap (letter size) of their route(s), GPS coordinates of each site, and standardized data forms. Most observers reported data over the internet via an on-line version of this data form, from which their data entered the database directly. Even those that reported via internet were instructed to return completed forms by mail. I entered data not reported via internet manually into the database.

Survey protocol

At each site one observer conducted a 5-minute, unlimited radius point count (Blondel et al., 1981), recording all bird species seen or heard. Observers conducted all counts between 30 min before and 4 h after local sunrise. Observers recorded the greatest number of individuals of each species known to be present during the 5-minute period. So that no data were discarded, observers recorded any observations by individuals other than the primary observer, outside the 5-minute window, or during transit between sites as separate, 'supplemental' observations. Counts were not conducted during periods of rain or prolonged drizzle, or if wind exceeded a gentle breeze (exceeded 3 on the Beaufort scale).

If noise was such that ability to detect and discriminate birds was compromised, observers were instructed to survey the site at a quieter time. Birds present around any type of land use within the study area (even parking lots and roads) are of interest. Therefore, site relocation to avoid road noise was only permitted if returning at a quieter time was not possible. Because original sites were placed randomly, observers were instructed to move inaccessible sites (e.g., in a residential back yard) to the nearest accessible location (e.g., sidewalk), and detail such changes with GPS coordinates, street addresses, and/or annotations on the provided maps. All analyses use actual count locations.

Data analyses

To evaluate the sensitivity of bird species to development, I analyzed the distribution of each species in the context of zoning maps. Zoning codes provide information on development mode and intensity, are readily available in the form of spatial data sets, and are the primary tool used in guiding land development. I condensed zoning codes used by area governments into 4 land use classes (Table 1), and used these classes to reclassify zoning GIS layers (Pima County Dept. Transportation, 2001) for the entire study area. The reduced number of land use classes was necessary to reconcile differences in zoning codes among the 4 municipalities involved and to minimize overlap among classes. For each species, I used a G test to test for differences in frequency of occurrence among land-use classes. Additionally, to identify the class or classes in which each species occurs most frequently, I tested for differences between each pair of land use classes. Because of the exploratory nature of this study, I used a fixed significance level of 0.05 for each statistical test. In addition to evaluating land use class ‘preference’, I computed the coefficient of variation among frequencies of occurrence in the 4 land use classes as a sensitivity index (SI) to characterize the sensitivity of each species to variation in land use.

Ecologists often use statistical methods to estimate species diversity from incomplete samples (e.g., Leitner and Turner, 2000). To assess the relationship between land use classes and bird species diversity, I estimated the number of species present in the study area as a whole and within each land use class using the first-order jackknife estimator (Burnham and Overton, 1979).

Biological data collected in the manner of the TBC provide a unique opportunity to evaluate quantitatively the bird community available for experience by people living in a metropolitan area. Doing so requires spatial information on bird species richness and on human population. For each 1 km^2 cell in the study area, neighborhood bird species richness was calculated as the total number of bird species observed in that cell and the 8 adjoining cells. This provides an index of the number of bird species present within a 9 km^2 neighborhood of each site in the survey area. Because of bias due to low sample size, this index was not computed at cells for which fewer than 5 neighboring cells were surveyed (e.g., some edges of the survey area). Census data on human population (2000 US Census data from Pima County Dept. Transportation 2001) were used to estimate the number of people living within each 1 km^2 TBC cell. Because census blocks are irregularly shaped and do not coincide with TBC cell boundaries, the proportion of each census block’s population occurring within a TBC cell was assumed to be proportional to the area of intersection between the census block and TBC cell. Summing across all census blocks intersecting a cell provides a reasonable estimate of the human population of each cell. Frequency distributions of species richness and human population among cells were then analyzed to quantify the bird community available to Tucson’s human residents near their homes.

Results

Survey effort

Between 15 Apr and 16 May 2001, 51 primary observers and 30 additional observers participated in the Tucson Bird Count. A few routes in the southern parts of the survey area went unadopted. Three other routes were adopted but not surveyed due to unrelated emergencies. Twenty of the 43 original sites at Davis-Monthan AFB were not surveyed due to access restrictions. Observers surveyed a total of 692 sites on 61 routes. Of these, data from 18 sites were discarded due to protocol violations (counts too late in the day or by observers who failed to meet the “skilled observer” criteria outlined above). Thus, valid data were obtained from 674 sites in the study area. To survey from accessible locations, volunteers moved sites a median distance of 27.9 m.

Survey effort – Year 2

In the TBC’s second year (15 Apr to 15 May 2002), 71% of primary observers returned from 2001. In 2002, a total of 53 primary observers and 25 additional observers participated. Six routes surveyed in 2001 were not in 2002 due to unrelated emergencies (these omissions are temporary, as the routes will be surveyed in future years). Eleven new routes were added. Valid data were obtained from 724 sites in 2002.

Two years of data are available. However, it is not yet profitable in most analyses to pool these data. This is because using only those 599 sites surveyed in *both years* would reduce the total number of sites available. One alternative would be to include all 799 sites surveyed in *at least one year* by averaging the counts at each site across years for those sites with more than one year available. However, this would produce potentially severe biases in analyses. For example, species richness (and the incidence of individual species) will be artificially lower at those sites surveyed during a single year than at sites surveyed both years. In the future, this bias will decrease, because one might use, say, all sites which have been surveyed in 4 of 5 years, 7 of 10, etc. But with two years' data this bias outweighs the benefit of including additional sites. Therefore, I report here the results of analyses using only the 2001 data (674 valid sites). Analyses conducted separately for 2002 data did not produce qualitative differences in results.

Bird community composition

Observers recorded a total of 104 bird species in point counts during the 2001 survey period. Of these, 77 species are considered actually or potentially breeding within the study area (hereafter, 'breeding species') based on breeding records and seasonal distribution notes (compiled in Taylor, 1999). Table 2 lists breeding species, their origin, seasonal status, and frequency of occurrence on the TBC. Because they are often difficult to separate reliably, data for Common and Chihuahuan Ravens were lumped for analyses. Of the breeding species, twenty-four are found in the study area only during the breeding season, while the remainder can generally be found in similar numbers year-round. In addition to the breeding species, 27 species of nonbreeders and transients were observed, collectively accounting for fewer than 1% of individuals counted. These nonbreeders include some species (e.g., Yellow-rumped Warbler, *Dendroica coronata*) which breed in the region but only at elevations above the study area.

While most species observed are native to the Tucson area, six species not historically present were observed. Three of these species are exotic, including the three European species (Rock Dove, House Sparrow, European Starling) common in many North American cities. The other three species (Inca Dove, Great-tailed Grackle, and Anna's Hummingbird) are considered 'near-native', having undergone range expansions in the past century. The first-order jackknife method estimated species richness for the entire survey area at 125 with an estimated standard error of 6.6 species. Figure 2 maps species richness observed across the study area.

Actual and estimated species richness varied among land use classes (Table 3). Both observed and estimated species richness were highest in Low-density Residential (RL), followed by High-density Residential (RH), Commercial/Industrial (CI) and Open Space (OS). However, these results must be interpreted with caution due to the disparate number of sites among land use classes. In fact, the rank order of land use classes by either observed or estimated richness is identical to the rank order of the number of sites per land use class. The jackknife method partially corrects for, but does not eliminate, the negative bias in observed species richness due to sample size.

Most non-breeding species were encountered rarely. This fact suggests that the study sampled the breeding species more thoroughly than it did the group of all species together. This may seem counterintuitive, but consider: many rare species suggest the presence of uncounted species, while lack of rare species among breeders indicates more complete sampling. This makes sense ornithologically as well, with breeding species generally more vocal and conspicuously positioned (and thus more readily detected) than non-breeders. Thus, richness estimates should be more accurate if applied to the breeding bird community alone. However, analysis of the breeding subset does not change the rank ordering of richness among land use classes (Table 3). The order does change slightly when only native breeding species richness is considered. Since only 2 of 6 non-native or near-native species were found in OS (compared to 6 in all other land use classes), OS surpasses CI in native breeding bird richness. Although not significant, this change occurs despite the much larger number of CI sites surveyed, suggesting that a greater diversity of species is indeed present in OS sites.

Species distributions

The stratified random approach enables the creation of species abundance maps over the Tucson area. These maps reveal some conspicuous qualitative patterns in the distribution of species. I discuss four common patterns here (Figure 3). Gambel's Quail, a distinctive Sonoran Desert bird, was among the most frequently observed species overall (395 sites), yet was notably absent near Tucson's urban center (Figure 3a). A suite of other desert dwellers (Ash-throated Flycatcher, Black-tailed Gnatcatcher, Black-throated Sparrow, Canyon Towhee, Gilded Flicker, Pyrrhuloxia, and others) exhibit similarly donut-shaped patterns.

The overall frequency of the exotic House Sparrow nearly equals that of Gambel's Quail (401 sites). However, the distribution of House Sparrows resembles the inverse of that of the Gambel's Quail, with many more observations in highly developed areas and fewer toward the urban periphery (Figure 3b). The Tucson-area distributions of other regionally synanthropic species (Anna's Hummingbird, European Starling, Great-tailed Grackle, Inca Dove, and Rock Dove) appear similarly skewed toward the urban center.

Lucy's Warbler was found most frequently to the northeast, an area containing mesquite forest and relatively tall trees of other native species (Figure 3c). Other species characteristic of native woodlands and streamside vegetation in the Sonoran desert, including Bewick's Wren, Brown-crested Flycatcher, Northern Cardinal, Lesser Goldfinch, and Phainopepla, showed similar patterns.

Abert's Towhee, an almost ubiquitous resident of riparian areas in much of the lower Colorado River watershed, was observed at only 8 of 674 sites. The distribution of these sites is informative, however: each lies within meters of a major wash (Figure 3d). The same is true of the sites at which Yellow Warbler (7 sites), Song Sparrow (3), and Common Yellowthroat (1) were observed. All are breeding birds typical of southwestern riparian habitats. Other species characteristic of these riparian habitats – including Summer Tanager (*Piranga rubra*) and Yellow-breasted Chat (*Icteria virens*) – were not observed at all.

Assessing avian sensitivity to land use

Quantitative analysis of bird and land use data provides insight beyond qualitative patterns in species distributions. Species showed wide variation in land use class preference (Table 4). Thirty-three species showed significant ($P < 0.05$) differences in their incidence among land use classes (G test across all classes in which species present). Pairwise G tests reveal 14 of these species occurring significantly more often in a single land use class. For the other 19 species, incidences in two land use classes were statistically indistinguishable from one another, yet significantly higher than in all other land use classes. Placing the four classes on a continuum from least developed to most developed (OS, RL, RH, CI), no species exhibited joint preference for nonadjacent land use classes. For example, while 10 species appeared to prefer both OS and RL, none preferred both OS and RH.

As revealed by the sensitivity index (SI), species also display wide variation in their sensitivity to differences in land use (Table 4). For example, although they were most common in RL and RH land use classes, White-winged Doves were found frequently in all classes (max. incidence = 84.8% in RH, min. = 61.1% in OS), and this is reflected in their low SI of 0.17. Other species insensitive to differences in land use include Mourning Dove (SI = 0.09; lowest of species occurring in > 5 sites), Curve-billed Thrasher (0.25), Gila Woodpecker (0.32), Cactus Wren (0.34), and House Finch (0.35). These SI values contrast strongly with those of Bell's Vireo (SI = 1.69), Canyon Wren (1.71; highest), and Phainopepla (1.47). Median SI among species occurring in more than 5 sites was 0.89. Perhaps one might expect uncommon species – seen in at most a few sites for any one land use class – to show spuriously higher SI values due to their low sample sizes. However, apparently insensitive-yet-uncommon species like Greater Roadrunner (SI = 0.35, 15 total sites) and sensitive-yet-common species like Ash-throated Flycatcher (SI = 1.29, 71 sites) indicate that SI remains a useful heuristic tool.

Avifauna experienced by Tucson's human population

Based on the 7,625 US Census blocks wholly or partially contained within TBC survey cells, approximately 515,000 people live within the 674 1 km^2 cells surveyed. Average number of species computed over a 9-cell (9 km^2) neighborhood was 21.6 (17.6 for native species). But people are concentrated in areas with fewer species: seventy-three percent (79.2% for native species) of the area's population has less than the average number of species in their 9-cell neighborhood.

Supplemental observations

In addition to the 104 bird species observed in point counts by primary observers, 4 additional species (one breeder and 3 nonbreeders/transients) were only counted outside of points counts or by other observers and were recorded as supplemental observations. Supplemental data also offer added distribution information for the 73 species recorded under supplemental observations for at least one site. Supplemental data required negligible additional effort to collect. Although acquired through less rigorous standards than point count data, supplemental data may nonetheless contribute to some studies (e.g., documenting that individuals of a species disperse to or investigate particular locations, but may not be establishing a population there).

Discussion

Once a discipline with few practitioners, the ecology and conservation of wild things in metropolitan areas is attracting more attention (see, e.g., Marzluff et al., 2001). The birds of Tucson alone have been the subject of multiple investigations (Emlen, 1974; Tweit and Tweit, 1986; Stenberg, 1988; Mills et al., 1989; Frederick, 1996; Germaine et al., 1998; Boal and Mannan, 1999). Yet, few studies have surveyed birds over an entire metropolitan area and its associated heterogeneities in land use. Citywide, systematic sampling of a metropolitan area has been attempted to varying degrees in the past in London (Montier, 1977), Porto Alegre, Brazil (Ruszczyk et al., 1987), Washington, D.C. (project 'DC Birdscape'; Hadidan et al., 1997), and Chiba City, Japan (Numata et al. 1997 as cited in Nakamura and Short, 2001). Although several of these surveys took multiple years to complete, none was repeated at the same sites to track changes over time. As discussed above, the otherwise unobtainable data of citywide studies offer great potential to advance conservation. However, once the critical mass needed to accomplish a citywide survey has been achieved, challenges include ensuring that the data contribute to scientific study and management, refining methodology as needed to improve the usability of data, and ensuring that the effort continues in the future.

The results and analyses presented here demonstrate the viability of volunteer-based, citywide surveys as research tools, and highlight some of the contributions possible with such projects. The Tucson area is home to a diverse bird community, yet distribution maps reveal that differences exist in how species respond to urban landscapes. Many TBC species maps fall into one of several recognizable patterns. Management for species diversity is impractical on a species-by-species basis, and distribution maps suggest groups that may respond similarly to management actions. Additionally, these maps may be used to identify potential sites for habitat preservation or restoration efforts. While other methods, such as targeted surveys of potential park areas, could provide information on species present, a citywide dataset provides baseline information that can be used to show how a site of interest compares to the rest of the metropolitan area. Indeed, TBC data have already been used in both of these roles (surveying site of interest and baseline data) in the purchase of land for a natural resource park. Distributional information collected in citywide surveys may also play a role in tracking the spread of introduced species or those with expanding ranges. Although not observed in the present study, two Old World species, Eurasian Collared-dove (*Streptopelia decaocto*) and Peach-faced Lovebird (*Agapornis roseicollis*), have been observed in the region (*pers. obs.* and T. Corman, *pers. comm.*, respectively) and may establish Tucson populations.

The analyses presented here demonstrate the effectiveness of citywide surveys in rapidly prioritizing species according to their sensitivity to development. They examine land use classes derived from area zoning classifications, revealing variation among species both in apparent preference for different land use classes and in sensitivity to differences in those classes (Table 4). As was the case with distribution maps, many species fall into groups with respect to land use preference and sensitivity. Future development is likely to affect most strongly those species that prefer classes of lower development intensity – OS and RL – and also show high sensitivity to differences in land use. In Tucson this group includes a suite of desert upland species (Black-throated Sparrow, Canyon Towhee, and others) and species more closely associated with wellvegetated washes (Lucy's Warbler, Bell's Vireo, and others). These results demonstrate the importance of open space to sustaining birds near cities. Zoning can be a useful tool in conservation (Bissel et al., 1986); the distributional, land use preference, and sensitivity findings of citywide surveys can inform its judicious use. This use of zoning can occur at local scales, in the form of regulating land uses near areas of particular importance to birds, and at regional scales, for example in maintaining adequate proportions of open space citywide.

Some caution is needed in the interpretation of these results. The notion of land use class used in this paper is a coarse descriptor of actual land use. Variation exists within each of the classes used, and lags can occur between the time of zoning changes and the time development occurs. In those cases where the land use class presented here does differ from actual land use at a site, land use class overestimates development intensity. For example, some large tracts at Davis-Monthan and on some state trust lands resemble open space in degree of development and vegetation, yet their zoning code allows low-density residential development. Thus, for the majority of species – those that fare more poorly at higher development intensities – the analyses here may slightly overestimate occurrence on higher-intensity land use classes and underestimate occurrence on lower-intensity land use classes. For these species, sensitivity index calculations are conservative estimates of actual sensitivity to development.

Initial results of the TBC indicate that a substantial diversity of birds may reside in developed areas, with low-density residential areas in particular appearing to harbor a number of species. This is a promising result, suggesting that opportunities indeed exist for integrating humankind and nature in the same landscapes. However, this result must be interpreted carefully. The fact that low-density residential areas contained more species than did, for example, high-density residential areas does not necessarily mean that preservation of nature is impossible in more densely developed areas. Rather, it simply reflects the fact that, historically, something about the way RL areas have been developed by humans has allowed the persistence of more species than the changes that took place in RH or CI areas. Ongoing investigation is focused on the more proximate mechanisms underlying these differences: what specific landscape features (e.g., amount and configuration of native habitat remnants) help sustain native bird species? It may very well be that, once these features have been identified, they may be used successfully in restoring birds even to more densely developed areas. This is particularly important considering that low-density development may be among the least desirable land uses in terms of negative environmental impacts (e.g., Anderson et al., 1996; see Roseland, 1998 for review).

The negative relationship between developmental intensity and bird diversity has been observed often, but has a tragic and seldom-considered consequence. As shown in the present study, due to the negative effects of urbanization (at least as it historically has occurred), the greatest numbers of Tucsonans experience the most impoverished bird fauna around the places they spend their lives. Globally, more than half of all humans are predicted to live in urban areas by the end of the decade (United Nations Population Division, 2001). If the analysis presented here is any indication, this translates to billions of people with fewer opportunities to interact with or develop an appreciation of the natural world. At first glance this pattern may appear trivial: perhaps we should expect a negative relationship between human population density and native bird diversity.

Thankfully, the relationship between humans and nature is more complex than that. That it is possible to sustain a diversity of living things in the places we live is a premise of the Tucson Bird Count's efforts, illuminating the methods by which we can sustain them the long-term goal.

Several computer technologies enabled management of the large amount of geospatial and count data needed to design and execute the TBC. I brought together existing data layers for roads, political boundaries, terrain features, land ownership, and zoning in a GIS. This GIS facilitated survey design, generation of maps, site location and relocation, and some spatial computations. A Structured Query Language (SQL)-capable relational database enabled web-based submission and organization of count data as well as real-time web display of results (Turner, 2002; JavaScript code for web interface available from author upon request).

With this common set of methods and tools in place, expansion of the survey area or inclusion of new monitoring programs requires marginal additional effort. The TBC began a pilot 'Park Monitoring Program' in 2001 to monitor specific parks, washes, and other areas important for birds more intensively than the main TBC program (data not shown here). Participants – both individuals and groups – adopted 13 parks to date and continue to survey them during 4 survey periods throughout the year, timed to assess wintering and migrating birds in addition to breeding birds. Although the program's methods differ slightly to better monitor non-breeding birds, existing TBC protocols and data management resources reduced the overhead needed to implement this new program.

Conclusions

In addition to pooling resources to facilitate science and management, large, volunteer-based surveys provide an avenue for urban conservation to engage a broader audience. Since its inception the Tucson Bird Count has had high visibility in the Tucson community. Since the bulk of urban lands are privately held, successful efforts to sustain nature in urban areas will require communication of results and recommendations to the public. Projects like this one – at the intersection of science, conservation, recreation, education, planning, and other fields – present opportunities for community-based conservation and other collaborative efforts.

Findings of the present study suggest that inclusion of open space parcels in the metropolitan landscape will be necessary for reviving and sustaining native bird communities. Additionally, developed areas should retain as much of the structural and vegetative character of open space as possible over a substantial part of the landscape. We already have several tools available for accomplishing this, including varying building density and – more practically – restoring and retaining native vegetation. Yet the tide has yet to turn. As with cities elsewhere, acres of native habitat are bladed for new development every day in Tucson, and every sale of an existing home brings a good chance of the new owner clearing existing vegetation. If this ratcheting effect continues, the spatial patterns of native bird species will be increasingly larger donuts around larger bird-deprived urban areas, and this can happen even if building densities remain unchanged. But we can turn the tide. Much research in landscape ecology remains to be done to develop practical solutions to sustaining birds in urban areas. More critically, we must inform the public of new and existing information and solutions. Though some may really have bad intentions or be truly indifferent, the majority of people simply aren't aware of the importance of yards, washes, and parks to creating a landscape more conducive to nature. This role as educator can only be filled by those of us studying urban systems.

The pioneering work of the North American Breeding Bird Survey (Sauer et al., 2001), DC Birdscape (Hadidan et al., 1997), and citizen science efforts of BirdSource and the Cornell Lab of Ornithology (e.g., Rosenberg et al., 1999) demonstrate some of what extensive, volunteer-based studies can accomplish. These projects also offer precedents for effective survey design, observer management, and data management which can facilitate other studies, as they have the present one. The Tucson Bird Count's first year was likely the most difficult, since most survey sites have now been established and data management tools have been created and tested. Apparently no citywide surveys have been repeated in additional years. The Tucson Bird Count expanded in its second year, and is scheduled to continue into the future. This project's continued success, and the establishment of others like it elsewhere, will depend on the ongoing participation of volunteer birders and the commitment of individuals and institutions to coordinate these efforts and see that their results continue to be used.

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Table 1: Land use classes represented in the study area. These classes condense zoning codes within the study area into four non-overlapping groups.

Land use class	Symbol	Description	Area (km^2)[a]	# sites[b]
Commercial/Industrial	CI	Industrial, office, business, and mixed development; parking lots	112.0	94
High-density Residential	RH	Single- and multi-family residential above 5.45 residences/acre (RAC; 8000 sq ft or 743 m^2 per residence)	173.8	176
Low-density Residential	RL	Single-family residential to 5.45 RAC, golf courses, urban parks	344.4	368
Open Space	OS	Natural reserves (Saguaro National Park, Coronado National Forest, Tucson Mountain Park)	43.6	36
Total			673.8	674

a Area within study area composed of each land use class. For this calculation, the total study area is the aggregate of all 1-km^2 grid squares containing visited sites. Total area adds up to less than 674 due to slight errors in rounding.
b Number of sites visited within each land use class. Because sites are classified according to the land use at the immediate count location, the number of sites is expected to approximate, but not equal, the actual area of each class.

Table 2: Breeding bird species observed in the study area on point counts during the study period. Only the 77 species actually or potentially breeding below 1000 m in the Tucson area are shown, including species found year-round and those generally present only during the breeding season.

Common name	Scientific name	Origin[a]	Season[b]	# sites	% sites[c]
Great Blue Heron	*Ardea herodias*	N	Y	8	1.2
Green Heron	*Butorides virescens*	N	Y	1	0.1
Black-crowned Night-heron	*Nycticorax nycticorax*	N	Y	1	0.1
Turkey Vulture	*Cathartes aura*	N	S	15	2.2
Mallard	*Anas platyrhynchos*	N	Y	5	0.7
Cooper's Hawk	*Accipiter cooperii*	N	Y	3	0.4
Harris's Hawk	*Parabuteo unicinctus*	N	Y	5	0.7
Swainson's Hawk	*Buteo swainsoni*	N	S	1	0.1
Red-tailed Hawk	*Buteo jamaicensis*	N	Y	15	2.2
American Kestrel	*Falco sparverius*	N	Y	10	1.5
Peregrine Falcon	*Falco peregrinus*	N	Y	1	0.1
Prairie Falcon	*Falco mexicanus*	N	Y	2	0.3
Gambel's Quail	*Callipepla gambelii*	N	Y	395	58.6
American Coot	*Fulica americana*	N	Y	2	0.3
Killdeer	*Charadrius vociferus*	N	Y	9	1.3
Black-necked Stilt	*Himantopus mexicanus*	N	S	1	0.1
Rock Dove	*Columba livia*	Ex	Y	170	25.2
White-winged Dove	*Zenaida asiatica*	N	S	539	80.0
Mourning Dove	*Zenaida macroura*	N	Y	610	90.5
Inca Dove	*Columbina inca*	NN	Y	57	8.5
Greater Roadrunner	*Geococcyx californianus*	N	Y	15	2.2
Burrowing Owl	*Athene cunicularia*	N	Y	2	0.3
Lesser Nighthawk	*Chordeiles acutipennis*	N	S	1	0.1
Common Poorwill	*Phalaenoptilus nuttallii*	N	S	1	0.1
White-throated Swift	*Aeronautes saxatalis*	N	Y	6	0.9
Broad-billed Hummingbird	*Cynanthus latirostris*	N	S	2	0.3
Black-chinned Hummingbird	*Archilochus alexandri*	N	S	39	5.8
Anna's Hummingbird	*Calypte anna*	NN	Y	61	9.1
Costa's Hummingbird	*Calypte costae*	N	S	8	1.2
Gila Woodpecker	*Melanerpes uropygialis*	N	Y	450	66.8
Ladder-backed Woodpecker	*Picoides scalaris*	N	Y	11	1.6
Gilded Flicker	*Colaptes chrysoides*	N	Y	66	9.8
Say's Phoebe	*Sayornis saya*	N	Y	9	1.3
Vermilion Flycatcher	*Pyrocephalus rubinus*	N	Y	4	0.6
Ash-throated Flycatcher	*Myiarchus cinerascens*	N	S	71	10.5
Brown-crested Flycatcher	*Myiarchus tyrannulus*	N	S	36	5.3
Cassin's Kingbird	*Tyrannus vociferans*	N	S	6	0.9
Western Kingbird	*Tyrannus verticalis*	N	S	26	3.9
Loggerhead Shrike	*Lanius ludovicianus*	N	Y	1	0.1
Bell's Vireo	*Vireo bellii*	N	S	6	0.9
Raven sp.	*Corvus cryptoleucus/corax*	N	Y	16	2.4
Purple Martin	*Progne subis*	N	S	24	3.6
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	N	S	9	1.3

Cliff Swallow	*Petrochelidon pyrrhonota*	N	S	2	0.3
Barn Swallow	*Hirundo rustica*	N	S	9	1.3
Verdin	*Auriparus flaviceps*	N	Y	290	43.0
Cactus Wren	*Campylorhynchus brunneicapillus*	N	Y	385	57.1
Rock Wren	*Salpinctes obsoletus*	N	Y	1	0.1
Canyon Wren	*Catherpes mexicanus*	N	Y	7	1.0
Bewick's Wren	*Thryomanes bewickii*	N	Y	6	0.9
Black-tailed Gnatcatcher	*Polioptila melanura*	N	Y	41	6.1
Northern Mockingbird	*Mimus polyglottos*	N	Y	285	42.3
Curve-billed Thrasher	*Toxostoma curvirostre*	N	Y	275	40.8
European Starling	*Sturnus vulgaris*	Ex	Y	153	22.7
Phainopepla	*Phainopepla nitens*	N	Y	68	10.1
Lucy's Warbler	*Vermivora luciae*	N	S	35	5.2
Yellow Warbler	*Dendroica petechia*	N	S	7	1.0
Common Yellowthroat	*Geothlypis trichas*	N	Y	1	0.1
Canyon Towhee	*Pipilo fuscus*	N	Y	33	4.9
Abert's Towhee	*Pipilo aberti*	N	Y	8	1.2
Rufous-winged Sparrow	*Aimophila carpalis*	N	Y	14	2.1
Rufous-crowned Sparrow	*Aimophila ruficeps*	N	Y	2	0.3
Black-throated Sparrow	*Amphispiza bilineata*	N	Y	61	9.1
Song Sparrow	*Melospiza melodia*	N	Y	3	0.4
Northern Cardinal	*Cardinalis cardinalis*	N	Y	143	21.2
Pyrrhuloxia	*Cardinalis sinuatus*	N	Y	75	11.1
Red-winged Blackbird	*Agelaius phoeniceus*	N	Y	8	1.2
Great-tailed Grackle	*Quiscalus mexicanus*	NN	Y	216	32.0
Bronzed Cowbird	*Molothrus aeneus*	N	S	17	2.5
Brown-headed Cowbird	*Molothrus ater*	N	Y	82	12.2
Hooded Oriole	*Icterus cucullatus*	N	S	8	1.2
Bullock's Oriole	*Icterus bullockii*	N	S	6	0.9
Scott's Oriole	*Icterus parisorum*	N	S	2	0.3
House Finch	*Carpodacus mexicanus*	N	Y	396	58.8
Lesser Goldfinch	*Carduelis psaltria*	N	Y	75	11.1
House Sparrow	*Passer domesticus*	Ex	Y	401	59.5

a Species origin: N = native; NN = near-native; Ex = exotic
b Seasonal status: Y = generally can be found in study area year-round; S = summer (breeding season) only
c Number of sites at which species observed expressed as percent of 674 total sites

(this page is Table 2, page 2 of 2).

Table 3: Species richness for species observed on point counts. Shown are observed species richness (SR) and first-order jackknife estimates (JK) ± estimated jackknife standard errors (SE).

	Land use class				
Species Group	**OS**	**RL**	**RH**	**CI**	**Total**
All species					
SR	43	94	64	52	103
JK±SE	60±5.7	117±6.8	87±6.8	69±5.8	125±6.6
Breeding/Potential breeding only					
SR	41	72	53	44	76
JK±SE	57±5.5	85±5.1	66±5.1	56±4.9	86±4.5
Native Breeding/Potential breeding					
SR	39	66	47	38	70
JK±SE	54±5.4	79±5.1	60±5.1	50±4.9	80±4.5

Table 4: Incidence among land use classes and sensitivity to differences in land use class among species. All species which showed significant differences in incidence among land use classes are shown.

Land use class[a]/Common name	Total # sites	Incidence (% of sites)[b] OS	RL	RH	CI	G^c	df	SI[d]
Open Space								
Ash-throated Flycatcher	71	44.4	13.0	3.4	1.1	55.95*	3	1.29
Gilded Flicker	66	30.6	13.3	2.3	2.1	41.41*	3	1.10
Black-throated Sparrow	61	47.2	9.5	5.1	.	38.01*	2	1.39
Black-tailed Gnatcatcher	41	22.2	6.5	4.0	2.1	15.22*	3	1.05
Canyon Towhee	33	25.0	6.3	0.6	.	28.38*	2	1.47
Canyon Wren	7	8.3	1.1	.	.	5.87*	1	1.70
Bell's Vireo	6	8.3	0.5	0.6	.	8.95*	2	1.68
Open Space and Low-density Residential								
Gila Woodpecker	450	69.4	76.1	65.3	31.9	63.04*	3	0.32
Cactus Wren	385	72.2	69.0	39.2	38.3	61.73*	3	0.33
Verdin	290	69.4	53.8	27.8	19.1	68.86*	3	0.54
Curve-billed Thrasher	275	44.4	46.2	36.9	25.5	15.30*	3	0.24
Northern Cardinal	143	22.2	29.9	11.4	5.3	45.91*	3	0.63
Pyrrhuloxia	75	11.1	15.2	6.8	3.2	17.50*	3	0.57
Brown-crested Flycatcher	36	16.7	7.1	1.7	1.1	19.16*	3	1.08
Lucy's Warbler	35	11.1	7.9	1.1	.	14.36*	2	1.06
Purple Martin	24	2.8	6.0	0.6	.	11.79*	2	1.16
Turkey Vulture	15	8.3	3.0	0.6	.	7.379*	2	1.27
Low-density Residential								
Gambel's Quail	395	52.8	80.7	30.1	27.7	177.30*	3	0.51
Brown-headed Cowbird	82	5.6	17.4	6.3	5.3	22.19*	3	0.67
Lesser Goldfinch	75	2.8	14.9	7.4	6.4	13.74*	3	0.64
Phainopepla	68	.	16.3	4.0	1.1	35.73*	2	1.40
Low-density and High-density Residential								
White-winged Dove	539	61.1	84.8	82.4	63.8	26.23*	3	0.16
High-density Residential								
House Sparrow	401	.	45.4	89.8	80.9	126.82*	2	0.75
European Starling	153	2.8	16.0	38.6	26.6	45.18*	3	0.72
High-density Residential and Commercial/Industrial								
Mourning Dove	610	77.8	88.9	95.5	92.6	12.82*	3	0.08
House Finch	396	27.8	54.6	71.6	62.8	29.86*	3	0.34
Northern Mockingbird	285	2.8	31.3	66.5	55.3	98.23*	3	0.72
Great-tailed Grackle	216	5.6	18.8	58.0	45.7	105.73*	3	0.75
Rock Dove	170	.	7.3	50.0	58.5	175.10*	2	1.02
Anna's Hummingbird	61	.	6.5	13.1	14.9	9.33*	2	0.78
Inca Dove	57	.	3.5	17.6	13.8	32.23*	2	0.95
Western Kingbird	26	.	1.9	6.3	8.5	10.98*	2	0.93
Commercial/Industrial								
Lark Bunting	7	.	0.8	.	4.3	4.63*	1	1.60

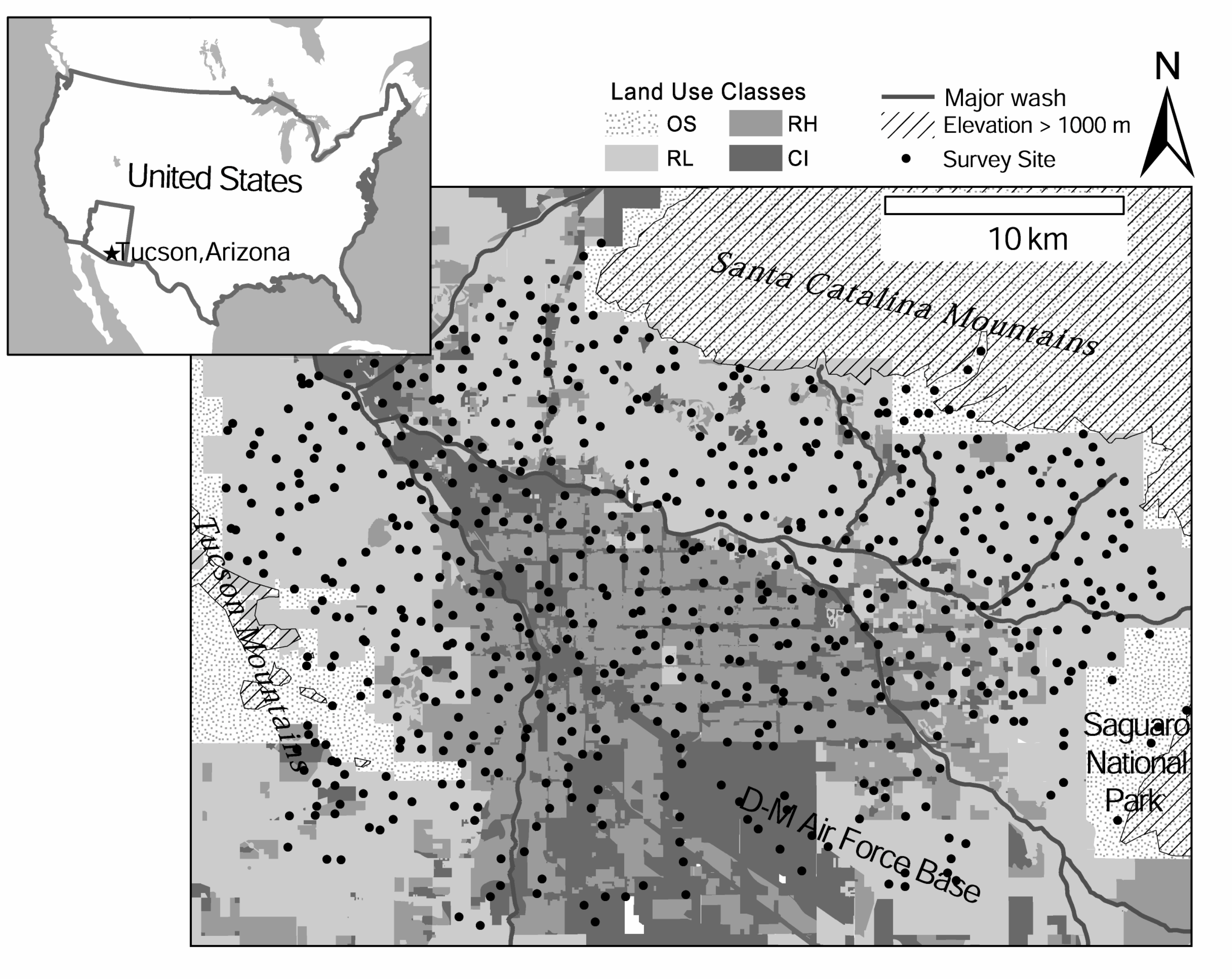
a Land use class(es) in which incidence significantly greater than all other classes at the $P < 0.05$ level. More than one class indicates incidence not significantly different among two classes of highest incidence, but incidence in each of these two significantly greater than all others.
b % incidence by land use class. See Table 1 for land use class descriptions.

c *G* statistic testing for deviation of incidences from equal incidence across all land use classes. * = $P < 0.05$.
d Index of sensitivity to variation in land use class, computed as coefficient of variation of fractional incidences among land use classes.

Figure 1: Map of the Tucson, Arizona study area showing land uses classes, major washes, and survey sites. Inset shows location of Tucson in western United States. See Table 1 for land use class descriptions.

Figure 2: Map of total bird species richness over the study area, showing total number of bird species in the 9 km^2 window encompassing each cell. Richness shown for all cells having 5 or more point counts within their 9 km^2 window.

Figure 3: Spatial distribution of abundance across the study area for selected species. Although each site was randomly positioned within a 1 km^2 grid cell, results are shown at cell centers for clarity. (A) Gambel's Quail. (B) House Sparrow. (C) Lucy's Warbler. (D) Abert's Towhee.



United States
Tucson, Arizona
Land Use Classes
OS
RH
RL
CI
Major wash
Elevation > 1000 m
Survey Site
N
10 km
Santa Catalina Mountains
Tucson Mountains
Saguaro National Park
D-M Air Force Base

Figure 1

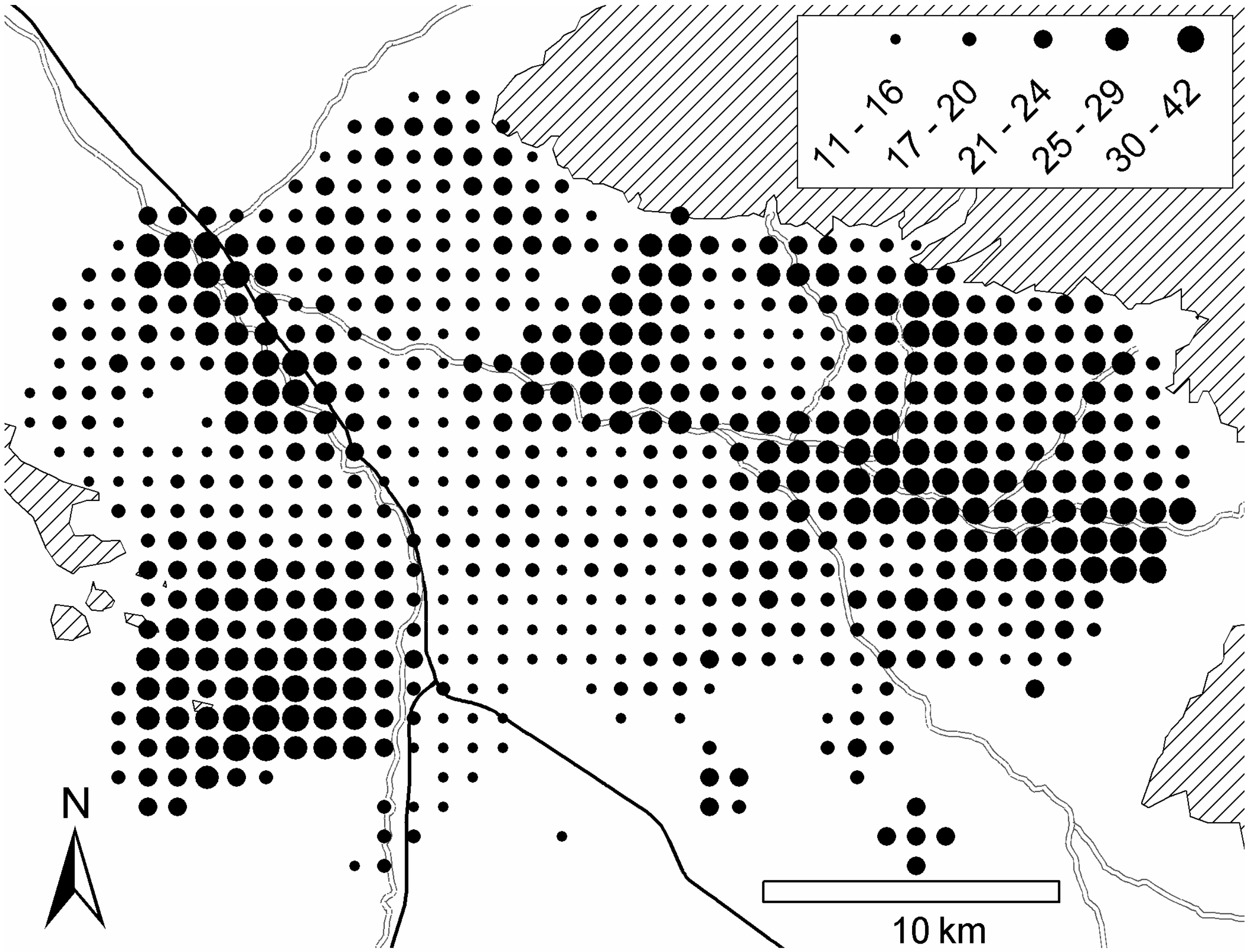


Figure 2

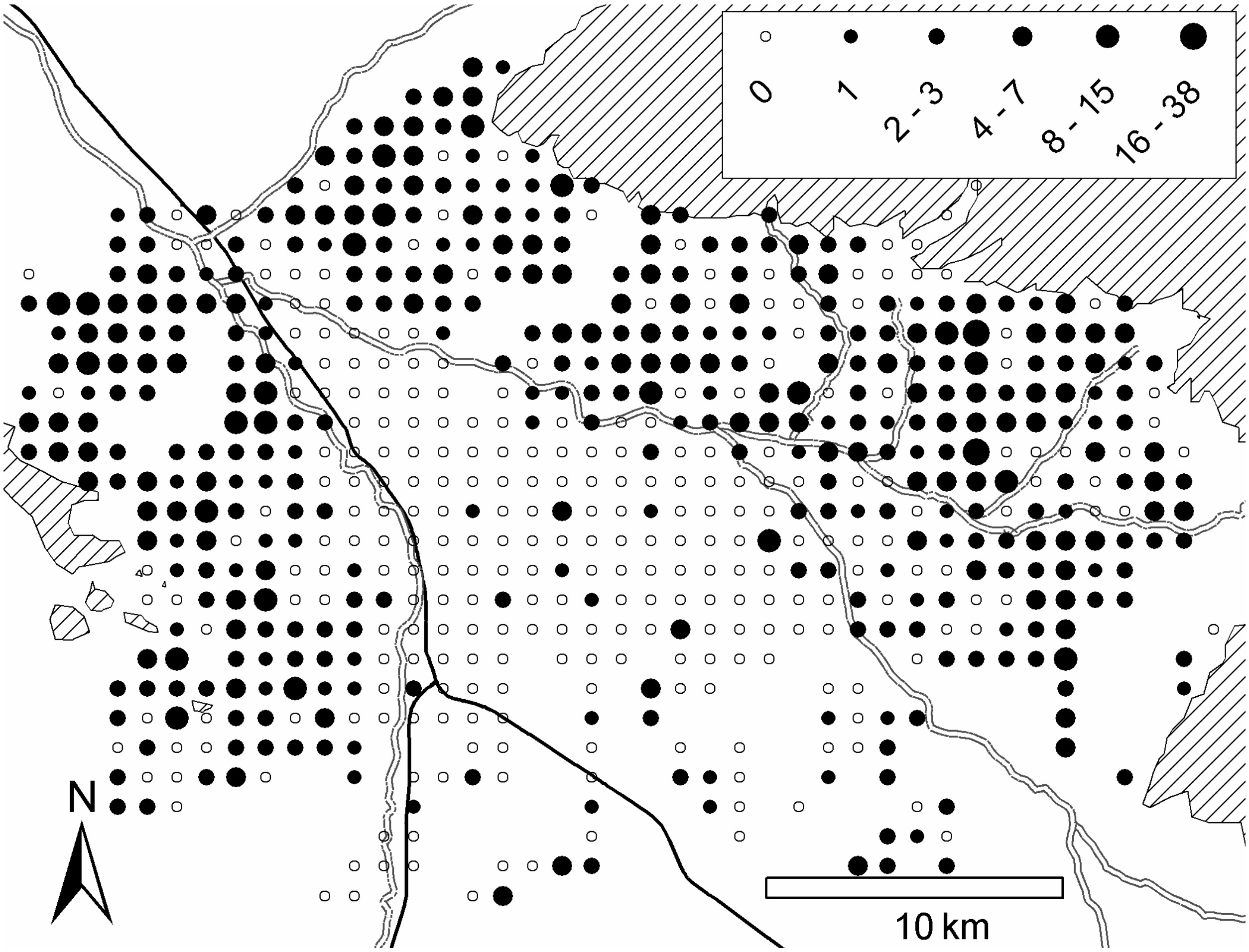


Figure 3A

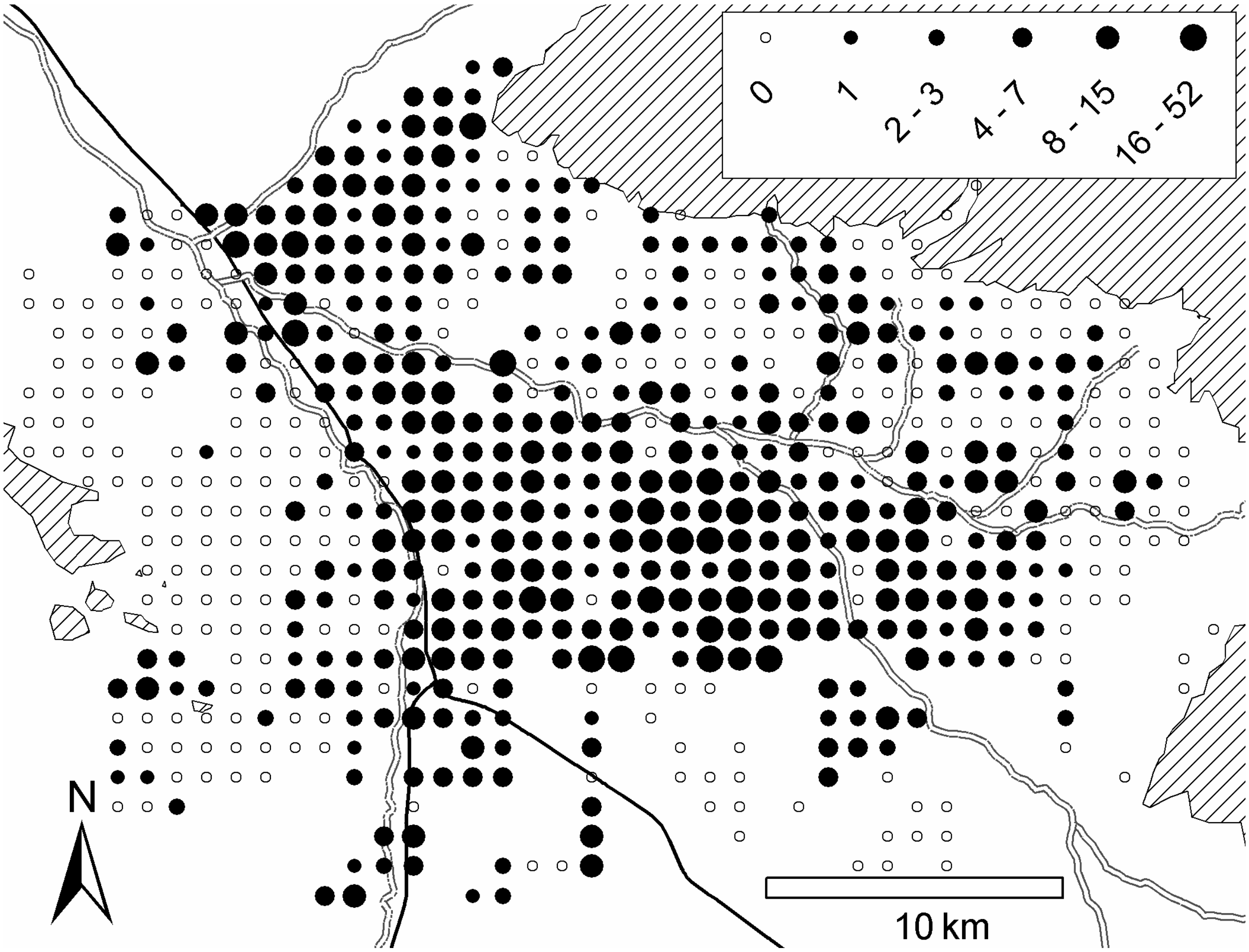


Figure 3B

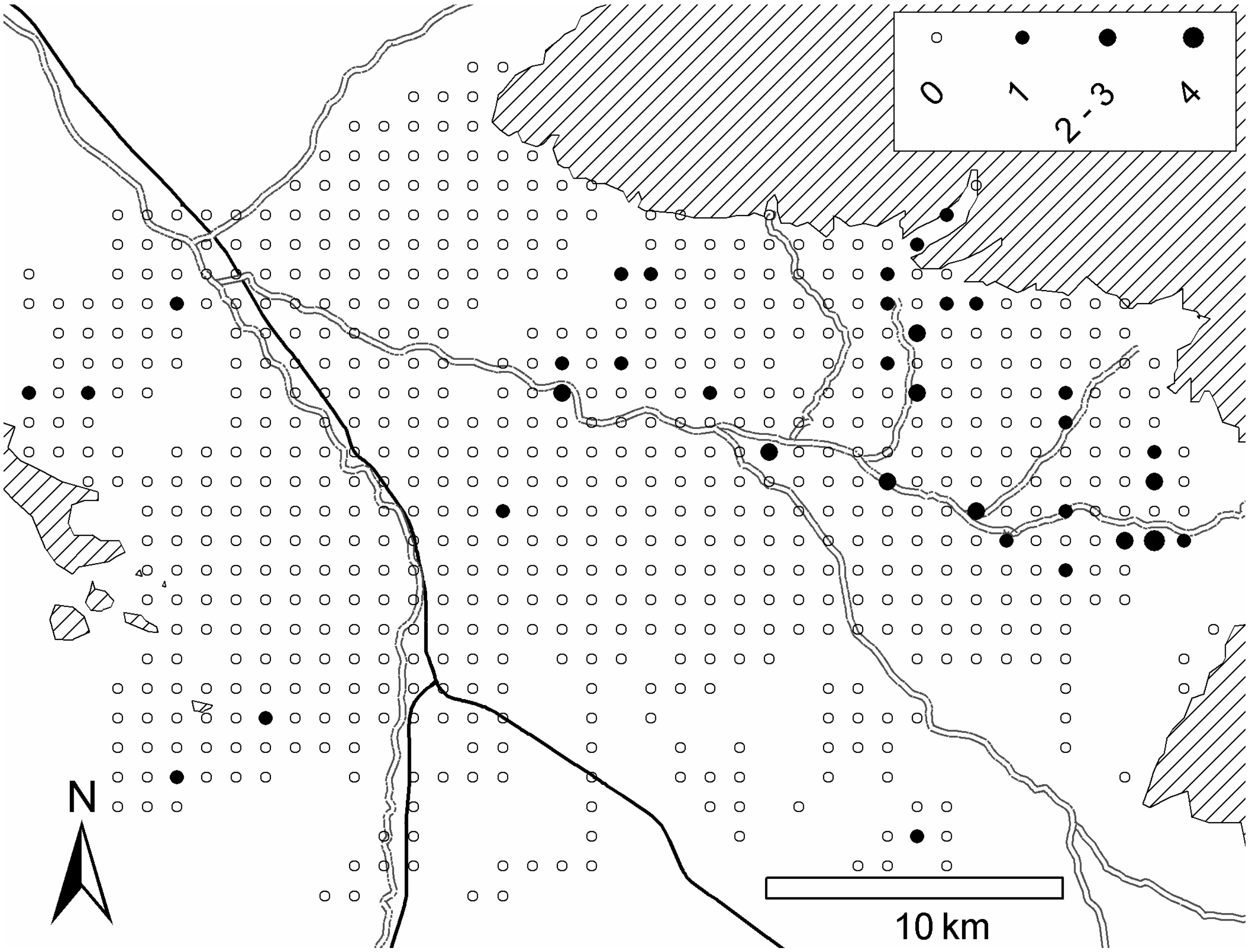


Figure 3C

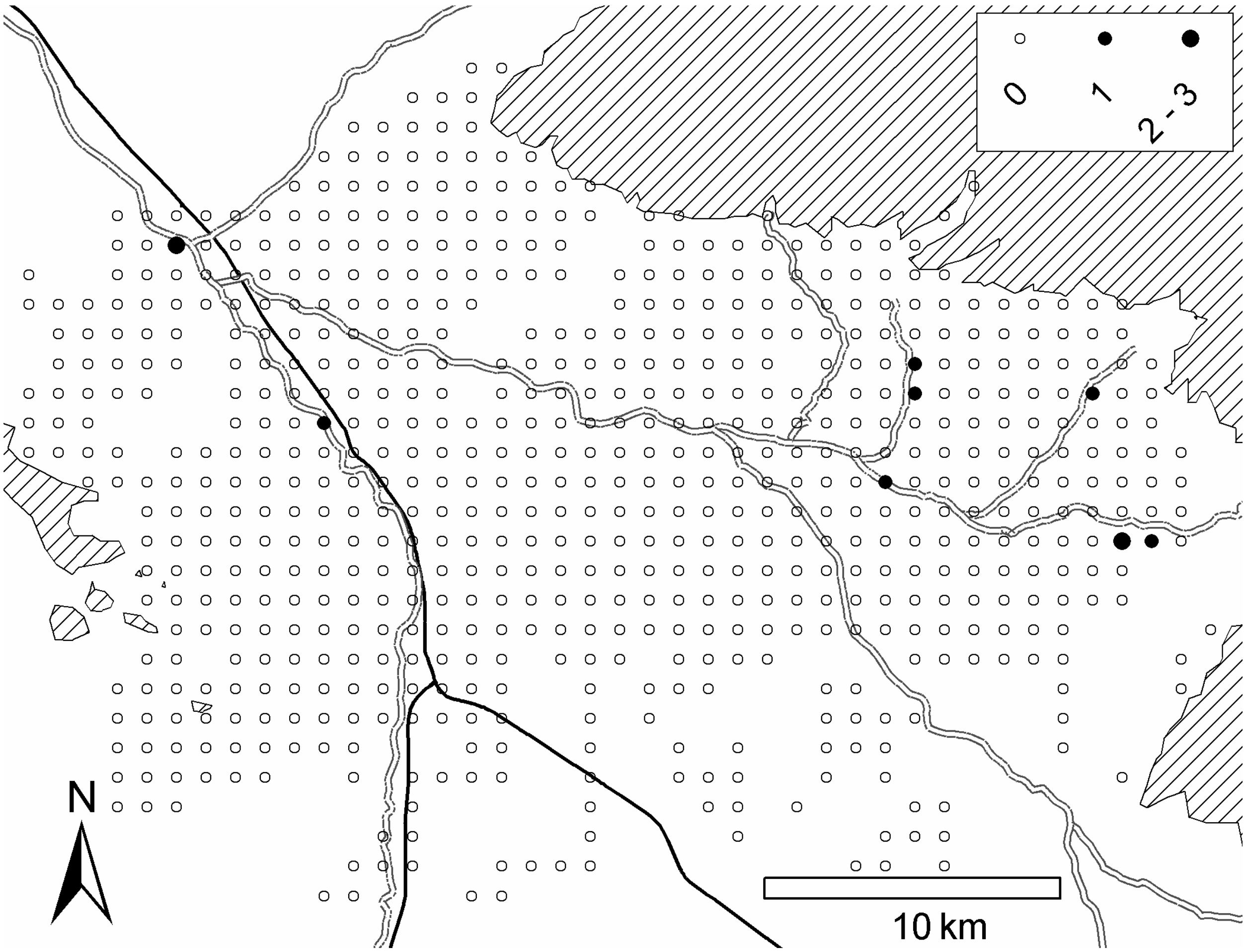


Figure 3D