Project Title: Determinants of Vertebrate Species Richness in an Urban Landscape

Cooperative Agreement Number: 1448-13420-01-J145

Date: 31 August 2005

Project Time Period: April 2002 through January 2004

Project Description:

Urban development has proceeded at a rapid rate in the United States and elsewhere, and one outcome has been an increase in habitat loss and fragmentation across North America. Urban centers are often located in some of the continent's richest habitats, and the impacts on natural biotic communities are unknown but potentially great. In that urban growth will increase inevitably in the future, it is imperative that we better understand how urbanization effects native plants and animals so that urban spaces can be designed to include parks and greenspaces (P&GSs) to serve as suitable wildlife habitat to minimize losses of native species.

Expected goals

With this objective in mind, members of the biology department at Portland State University (Primary Investigator: Michael T. Murphy) undertook a two year study to (a) survey and document species richness of terrestrial vertebrates in Portland's P&GSs, and (b) identify the correlates of variation in richness and diversity of native and non-native species. The objective of the latter goal was to provide information to allow managers to define minimum acceptable P&GSs size, shape and connectivity to help maintain biodiversity in protected sites. Our emphasis was on natural (undeveloped) and upland (i.e., non-riparian) forest communities with a mixed conifer-deciduous tree composition. We chose to focus on upland communities because a previous study in Portland had been conducted on riparian communities. Although not an original project goal, we also conducted surveys of plant communities within the P&GSs. Survey data for birds and plant were collected from 48 P&GSs, while data for mammals and amphibians came from a subset of 25 and 17 of the 48 P&GSs, respectively. All sites (except Oxbow Regional Park) were located within the urban growth boundary, and data were collected over a 32 month period. Participants included the primary investigator, three graduate students (David C. Bailey, Nathan I. Lichti, and Laura A. Roberts), three field assistants, and 16 volunteers. The team of people amassed well over 6,000 person-hours in the field and over 1000 person-hours in data reduction, analysis, and preparation of theses. The project produced two Masters theses (and soon a third), and public presentation of results at annual meetings of The American Society of Mammalogists (2), The Ecological Society of America (1), The Annual Meeting of the Oregon Chapter of the Wildlife Society (5), The Regional Meeting of the Society for Ecological Restoration (1), and annual meetings of the Urban Ecology Research Consortium (5). (The number in parentheses refers to the number of talks and/or posters given.) We expect to publish 5 to 6 papers in peer review scientific journals describing our results within the next year.

Actual accomplishments

Although our original project description focused solely on documenting terrestrial vertebrate communities, we found it essential that we also survey and quantify the plant communities within all of our study P&GSs. An unintended benefit was therefore a rigorous description of plant community diversity and structure. I will therefore describe our accomplishments beginning with the forest plant communities and then proceed on to describe the amphibian, mammal and avian communities.

Plants. - We sampled plant communities at 279 points in 48 P&GSs and included quantification of the tree, shrub and herbaceous layers. We identified 134 species, of which 34 were woody plants (shrubs or trees). We examined the effects of (a) patch size (area of the P&GS), (b) patch shape, (c) landscape composition, and (d) underlying geophysical structure on diversity of total, and both native and non-native plants in all P&GSs. Landscape features were quantified in a one kilometer diameter buffer around each park using ArcGIS and FRAGSTATS, and included categorization of buffer space as belonging to 1 of 8 land uses (forest, developed areas with canopy trees, developed areas devoid of trees, developed parks, agriculture, open water, residential, and commercial). Our analyses also corrected for spatial variation in the distribution of plants across the urban landscape. We found that the diversity of native woody plants increased with patch area and declined as patches took on more complex shapes. Ultimately, this meant that the highest native diversity was found in parks that were large and in which the amount of interior space was high compared to the amount of edge. Conversely, the richness of non-native woody species was greatest in small parks that were characterized by large amounts of edge habitat. In other words, small parks that tended to be long and thin contained the most non-native species. Landscape factors appeared to have little influence on the distribution of woody species. Native herbaceous plants were most diverse in P&GSs that were topographically complex and which had little commercial or industrial development in the surrounding landscape, while non-native herbaceous plant diversity increased as P&GS area declined. Thus, the diversity of native plants was best served by P&GSs that were large, located in topographically complex locations, and in which the surrounding landscape had little industrial or commercial development. Our data further suggested that native plant diversity was best maintained by landscapes in which the surrounding buffer retained large amounts of canopy tree cover.

Amphibians. – We sampled amphibian diversity and abundance using a combination of standard pit fall arrays, incidental observations, and stream sampling in 17 P&GSs over three sampling seasons (spring and fall between 2002 and 2004). A total of 9 species was recorded in 22,948 trap nights, while a 10th was added from the stream surveys. Total species richness and total abundance was examined in relation to variables at three spatial scales: (a) local microenvironment, (b) macrohabitat/patch, and (c) landscape. Variables at the microenvironment scale included physical structure of the sampling site (e.g., herbaceous plant density, density of logs/snags) and physical conditions that may directly affect amphibian activity (e.g., soil moisture and soil pH). Macrohabitat variables included P&GS area and shape, elevation and slope, and plant community structure. Landscape variables were similar to those described for the plants. Our results showed that native amphibian diversity was influenced most by factors at the macrohabitat/patch scale and that richness was highest in P&GSs that were large, and in which the tree community was dominated by deciduous trees. Furthermore, richness was greatest at sites where the density of shrubs above a height of 1 m was high. On the other hand, abundance of amphibians responded most to microenvironmental variables, with abundance increasing directly with soil moisture and declining with increasing soil temperature. More captures were also made where the ground was relatively bare. The latter result may simply reflect greater ease of movement and detection of salamanders, rather than directly indicate a positive habitat feature. Our statistical analyses detected little relationship between landscape features and amphibian richness and abundance. Species richness within P&GSs is similar to that of nonurbanized sites within the region, but abundance is low compared to these sites. It is unclear whether the low abundance reflects real differences or a response to relatively dry conditions over the period of our work.

Mammals. - Surveys of mammalian diversity were conducted in 25 P&GSs using live-capture methods. We captured a total of 2,146 individuals of 14 species (4 non-native and 10 native) in over 27,000 trap opportunities. We employed rarefaction methods in our analyses to correct for unequal trap effort (small parks unavoidably had fewer trap opportunities) to enable direct comparisons of diversity among parks of different sizes. It is important to note also that our conclusions are limited to species that were able to be captured in standard small mammal traps, and therefore does not sample for mammal species exceeding roughly 400 g. We again tested for effects of (a) P&GS characteristics (size and shape), (b) habitat features (plant species diversity, presence/absence of water, and structural diversity [e.g., tree size, density of logs and snags, ground cover, and canopy cover]), and (c) landscape structure in the 1-km buffer surrounding each P&GS (see above) on mammalian diversity. Rarefacted species richness of native mammals was highest in P&GSs that were large and which contained wetlands and/or streams. Native diversity also increased as the surrounding landscape became less urbanized and was instead characterized by high canopy tree cover in the surrounding neighborhoods. Non-native mammal diversity, on the other hand, was greatest in small P&GSs surrounded by urbanized landscapes. Our analyses suggest that small mammals typical of Pacific Northwest forest experience extinction in urban landscapes as fragmentation increases, as a combination of both isolation from other patches and degradation of habitat due to edge effects. Overall, maintenance of habitat connectivity among P&GSs appears to be critical for maintaining diversity of native small mammal species.

Birds. – Our surveys for avian richness were conducted at 22 sites in 2002 and at all 48 sites in 2003. We used standard point counts (10 minutes/count) at an average of 4 sites/P&GS. All counts were conducted before 11 AM and between late May and the middle of July so as to avoid the major pulse of migration and limit detections to resident breeding birds. No attempt was made to survey for nocturnal species (owls or nighthawks) and therefore our results are restricted to diurnally active species. We detected a total of 61 species, with a range of between 14 and 36 species/P&GS. Elimination of rare species and "fly overs" (i.e., species only observed flying above the canopy) reduced the number of species to 51. Of the three possible non-native species, Starlings (*Sturnus vulgaris*) and House Sparrows (*Passer domesticus*) were detected, but both were very uncommon. Thus, the avian communities within forest P&GSs are native communities similar in composition to sites outside the urban growth boundary. Our analyses have not yet been completed, but we plan to address similar issues as those described above for other taxa. Species richness and abundance will be examined in relation to (a) P&GS area and shape, (b) plant species composition and habitat structure, and (c) landscape composition and connectivity. Our very preliminary analyses indicate that diversity of long distance, intercontinental migrants increases with P&GS area, and is positively associated with shrub density within the P&GS. On the other hand, richness of year-round resident species decreased with P&GS area, and among short-distance migrants (migrate but remain within North America) there was no relationship between richness and area. Final conclusions await simultaneous evaluation of P&GS features, and both habitat and landscape variables.

Work Tasks and Project Schedule:

Preliminary work (prior to submission of original proposal): Selection of possible study sites, followed by ground truthing to verify suitability.

April/May 2002:
- Construction of pit-fall arrays in 13 P&GSs for sampling amphibians
- Establish 44 line transects for trapping mammals in 15 P&GSs
- Location of 95 points in 22 P&GSs for avian surveys

June 2002 through July 2002
- Daily trapping and surveys for all taxa

July 2002 through the first week of September 2002
- Sample vegetation at all survey points (for amphibians, birds and mammals) in all P&GSs

September 2002 through mid-November 2002
- Conduct fall surveys for amphibians

September 2002 through May 2003
- Input data and initiate landscape surveys using RLIS dataset obtained from METRO

February 2003 through June 2003
- Establish pit-fall arrays at four additional P&GSs, and conduct amphibian surveys at all 17 sites. Locate an additional 26 new P&GSs for inclusion in study of plants and birds for upcoming year

May 2003 through mid-July 2003
- Establish transects for mammals at 10 new sites, bird survey points at 26 new sites, and conduct daily surveys for birds and mammals

Mid-July 2003 through August 2003
- Conduct plant surveys at all 26 new sites

September 2003 through April 2004
: Complete ArcGIS analyses of landscape variables for all 48 sites, finish data analysis for amphibians and mammals, and write theses for amphibians (Roberts) and mammals (Lichti)

May 2004 through July 2004
: Write and defend theses (Roberts and Lichti)

Summer 2005
: Continued analysis of data and preparation of reports.

Project Staff and Partners (including volunteers):

1. **Salaried Staff**

   Michael T. Murphy, Project Supervisor
   David C. Bailey, Graduate Student and Research Assistant
   Nathan I. Lichti, Graduate Student and Research Assistant
   Laura A. Roberts, Graduate Student and Research Assistant
   Zac Harlow, Field Assistant
   Jeremy Williams, Field Assistant
   Suzanna Kruger, Field Assistant

2. **Volunteers**

   Jenny Carwile (84 hours)
   Erin Crowell (84 hours)
   Krista Dake (48 hours)
   Lisa Davis (84 hours)
   Amy Dolan (83 hours)
   Krey Easton (40 hours)
   Kim Freemal (90 hours)
   Paula Graaf (84 hours)
   Lilian Herron (48 hours)
   Kelly Hoffman (345 hours)
   Pamela Johnston (84 hours)
   Ariana Kramer (72 hours)
   Natasha Nikolaidis (84 hours)
   Luke Redmond (113 hours)
   Keith Robillard (71 hours)
   Suzanna Kruger (660 hours)

   Total volunteer hours = 2,074
   The total does not include time that other paid group members helped others with their projects (an additional 56 hours).

3. **Partners**

   Metro Regional Services
   City of Durham
   Oregon State Parks
   City of Gresham

City of Lake Oswego
City of Troutdale
Riverview Cemetery Association
Clackamas County
Lake Oswego United Church
Three Rivers Land Conservancy
Tualatin Hills Parks and Recreation District
City of Portland
City of West Linn
Lake Oswego High School
Mt. Scott Church of God

Map of Project Area and Study Locations:
(Names and features of numbered locations given on following page)

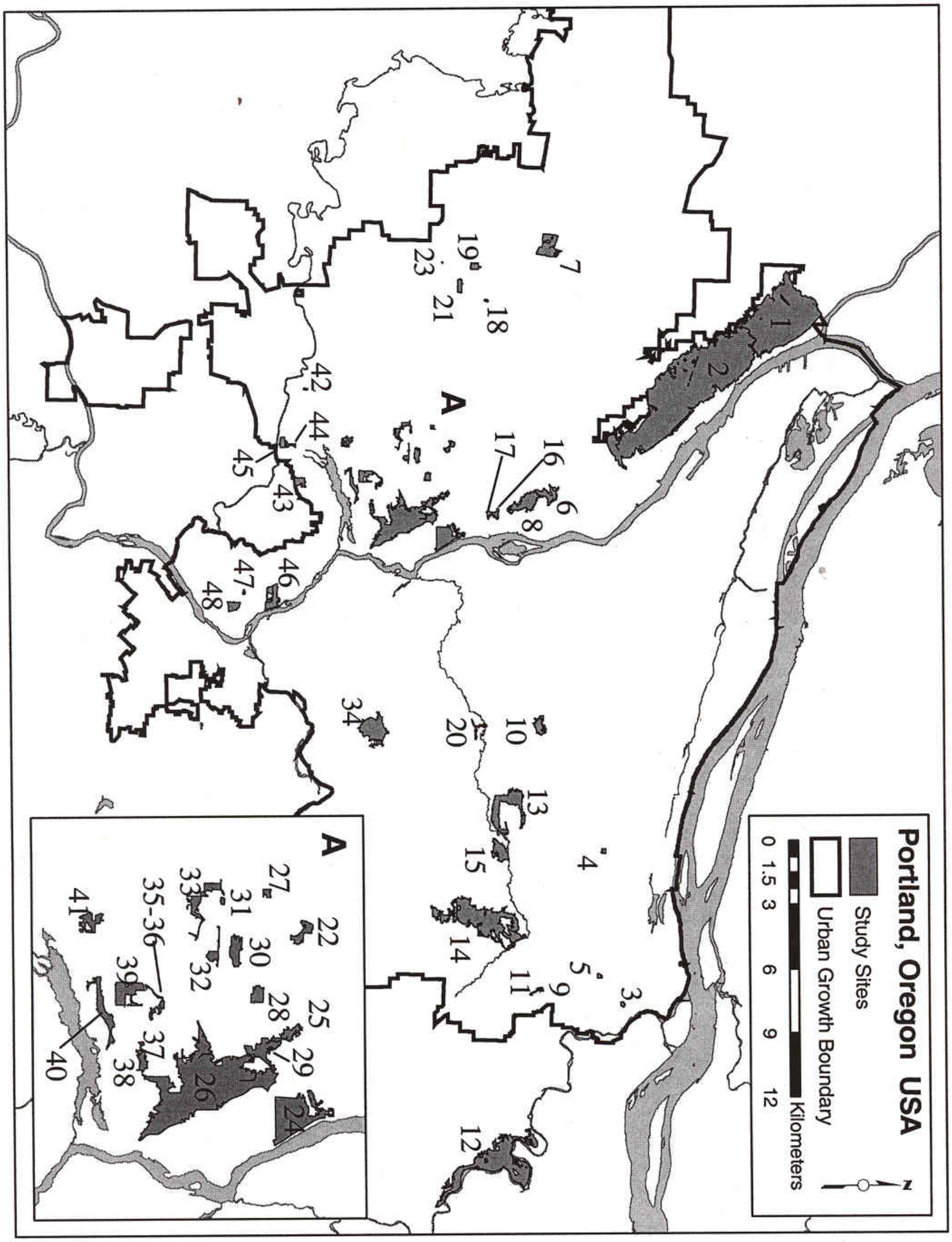

Fig. 1. Map of 48 study sites within the Portland, OR, urban growth boundary. Numbers below correspond to those given on the map.

Site ID	Site name	Area (ha)
1	Forest Park North	731.8
2	Forest Park South	1538.4
3	Columbia Park	3.6
4	Nadaka Park	3.7
5	Helen Athalos Park	3.7
6	Marquam Park	38.9
7	Tualatin Hills Nature Park	72.0
8	Keller Woodlands	71.7
9	Kane Road North	1.2
10	Kelly Butte	29.3
11	Kane Road South	4.4
12	Oxbow Regional Park	390.1
13	Powell Butte	129.0
14	Gresham Butte	354.3
15	Jenne Butte	49.4
16	George Himes North	8.9
17	George Himes South	5.7
18	Fir Grove Park	1.6
19	Lowami Hart Woods	11.8
20	Mt. Scott Church	9.0
21	Hyland Forest Park	11.7
22	Woods Memorial Park	11.1
23	Shaughnessie Park	0.3
24	Riverview Cemetery	80.5
25	Marshall Park North	10.4
26	Tryon Creek State Park	288.3
27	Dickinson Park	2.7
28	Maricara Park	11.0
29	Marshall Park South	22.1
30	West Portland Park	14.1
31	PCC Sylvania Parking Lot	1.3
32	Kerr Park	5.3
33	Lesser Park	18.3
34	Mt. Talbert	114.0
35	Lake Oswego HS North	3.7
36	Lake Oswego HS South	2.0
37	Lake Oswego Church	0.8
38	Smith Woods	7.9
39	Springbrook Park	23.0
40	Iron Mountain	21.8
41	Walluga Park	13.8
42	Durham City Park	1.4

43	Cook's Butte	17.9
44	Bryant Woods Park	6.4
45	Canal Acres Natural Area	13.1
46	Mary S. Young State Park	47.5
47	Sahallee-Illahee Park	1.8
48	Wilderness Park	19.8

Methods:

Plant sampling. – We sampled vegetation at all points where the vertebrate taxa were sampled (n = 279, range = 2 to 16 per P&GS). At each point all vegetation and structural features within a circle of 10 m radius were sampled. All trees within every circular plot were identified to species and diameter breast height (DBH) recorded. Shrub density, herbaceous cover, and canopy cover were evaluated every two meters along two perpendicular transects that crossed in the middle of the plot. Ground cover features were also recorded at every two meters along the transects, and the total length and average DBH of standing dead trees ("snags") and downed trees ("logs") were recorded to allow calculation of total volume of snags and logs. We also recorded distance to trails and water, elevation, slope and aspect, and determined percentage ground cover by native and alien species. Landscape data were collected as described above, and data analyses proceeded by evaluating plant species richness in relation to P&GS features, geomorphology, and landscape features using principal components, partial canonical correspondence, and stepwise multiple regression analyses.

Amphibian sampling. – We relied primarily upon captures from pit-fall arrays to describe amphibian richness. The pit-fall traps were 3.5 gal buckets that were sunk so that the top of the bucket was flush with the ground. A pit-fall array was a system of four buckets arranged in a Mercedes Benz design (1 in the middle and 3 arrayed at 120^{o} outward from the middle; outer buckets placed 5 m from the center). Drift fences (constructed of landscaping cloth) ran from the central bucket to the three buckets on the perimeter to intercept moving amphibians and direct them towards the buckets. All buckets were covered during non-sampling periods with a tight lid (with a rock placed on top to prevent accidental opening). Trapping periods included spring/early summer 2002, fall 2002, late winter/spring 2003, and then fall 2003 (up to and including January 2004). In 2002 buckets were kept open for three consecutive days and checked on the third. During periods when the buckets were open a stick that extended from the bottom to the top of the bucket was placed inside to allow small mammals to escape. We changed protocols beginning in fall 2003 and kept buckets open for five consecutive days and checked them daily. Incidental observations (both visual and auditory) of amphibians were made during all visits. In summer 2003 we also conducted stream surveys within all parks with flowing water. We randomly selected one stream within each P&GS, and then randomly selected a 10 m length of the stream (including the stream bank) to overturn all rocks and logs to detect stream dependent species. In 2003/04 we also sampled soils at all pit-fall arrays to quantify ground cover, and soil moisture and pH. We analyzed total diversity (from pit-fall arrays, incidental observations, and stream samples) in relation to P&GS features, microenvironmental variables, and landscape characters using principal components and stepwise multiple regression analyses.

Mammal sampling. – Mammals were sampled using Sherman and Tomahawk live traps that were placed at 10 m intervals along 100 m long randomly selected transects. Trapping took place during the late spring (May) and on into summer (late August). We placed 1 to 4 transects within each P&GS (dependent upon size of P&GS). Traps were baited with rolled oats/peanut butter or sunflower seeds. To minimize trap mortality, each trap was covered with a board and provided with batting for insulation. Traps were set just before dark and checked less than 12 hours later. Upon capture animals were identified to species, weighed and measured, sex and age class determined when possible, and ear tagged to allow for individual identification (not possible for species with extremely small external ear pinnae). Trapping sessions consisted of four consecutive nights of trapping in each P&GS, and the total number of animals captured was tallied. We recorded data for diurnally active species that were less likely to be captured by the traps by making visual/auditory observations from point counts (1 to 6 per P&GS). Because of the unequal trapping effort (the number of transects increased with P&GS area), we conducted rarefaction analyses to standardize captures to a common trapping intensity. We then examined rarefacted species richness in relation to P&GS features, habitat structure and landscape structure using principal components and stepwise multiple regression analyses to identify the primary predictors of mammal species richness.

Bird sampling. – We used standard 10-min point counts to record individuals of all species. The number of point count stations varied between 1 and 6 per P&GS (the number again was dependent upon P&GS size). Stations were randomly located within the P&GS with the proviso that each station had to be located a minimum of 50 m from the edge of the P&GS. Counts were timed seasonally to minimize including migrants, and were conducted from just after dawn until 11 AM. All individuals seen or heard were marked on a schematic of the plot to keep track of locations and movements, and the total number of individuals of each species was recorded at three distance intervals: 0 to 50 m, 50 m to 100 m, and beyond 100 m. All P&GSs were sampled thrice per season, and the largest of the three counts per station was used as an estimator of bundance for that species. We again used rarefaction methods to control for the different number of point counts at P&GSs and used the rarefacted estimates of abundance in our analyses. Final statistical analyses of the count data are currently underway.

On-going Tasks and Continued Activities:

Although the majority of our work is completed we have several important tasks in need of further work. Most significantly is the need to complete the analyses describing the determinants of variation in avian richness. This particular task has, in part, been slowed by the birth of a child to one of the projects primary researchers (David Bailey). However, I am resolved to have this portion of the project completed by the first of the year (January 2006). Bailey undertook this phase of the research as the research component for his Masters thesis, and if he does not complete the project by the first of the year I will take the data and complete the analyses myself.

Equally important is the submission of manuscripts for peer review for publication in scientific journals. Progress on this front has been temporarily halted while we correct for several errors that Bailey detected while attempting to complete his analyses. ArcGIS is a rather cumbersome piece of software and its workings are not particularly well documented. Lichti's and Robert's analyses were therefore conducted (unbeknownst to them) with errors and we have to redo those analyses before manuscripts can be submitted. We are in the process of doing this now. The nature of the errors are quantitative, not qualitative, and therefore we do not anticipate major changes to our conclusions. Nonetheless, we need to redo the analyses to ensure accuracy. I expect that this will be completed this fall and that manuscripts will be submitted by January 2006.

Once separate analyses of all four taxa (amphibians, birds, mammals and plants) are completed I plan to conduct a synthetic analysis of total biotic diversity that will incorporate the full body of information. We will be able to examine total biotic diversity within 17 P&GSs for which we will have information on patch characters (size, shape and connectivity of P&GS) and landscape features. It will be a truly unique study because no other study of which I am aware has so thoroughly examined diversity of different taxa. This will be submitted for peer review and publication.

Finally, work is continuing (funded from a separate USFWS proposal) to examine demographics of avian populations in Portland P&GSs. This project grew out of the current work and is proceeding very efficiently. I hope to attract new students to continue this work, and to follow up on additional studies to monitor long-term trends of diversity that we have detected in the research funded by this project.

Summary of Expenditures and Project Costs:

Expenditures

I. Salaries and wages	
Murphy, M. T. (PI)	$8,050.00
Bailely, D. C. (graduate student)	$12,240.00
Lichti, N. I. (graduate student)	$12,240.00
Roberts, L. A. (graduate student)	$10,649.95
Herron, L. (graduate student)	$1,500.00
Kruger, S. (research assistant)	$4,080.00
Williams, J. (research assistant)	$3,600.00
Harlow, Z. (research assistant)	$2,250.00
Hourly student wages	$425.00
Total salaries and wages	**$55,035.45**
II. Fringe benefits	**$3,795.18**
II. Materials and supplies	**$8,545.63**
Total direct costs (from USFWS)	**$67,376.00**

Match

I. Salary and stipends	
PI (Murphy) salary @ 10% of 1.0 FTE)	$12,705.86
Student teaching assistant stipends	
Lichti (16 Sept. 2001 to 15 June 2004)	$26,908.02
Roberts (16 Sept. 2001 to 15 June 2004)	$28,579.02
Bailey (part of 2002 and 2004)	$7,951.98
Herron (16 Sept. 2003 to 15 March 2004)	$6,666.00
Total salary and graduate student stipends	**$82,810.18**
II. Graduate student tuition remittance	
23 terms (9 Lichti, 9 Roberts, 3 Bailey, 2 Herron) @ $3,300/term	**$75,900.00**
III. Volunteer hours	
Total volunteer hours = 2,074 @ $7.25	**$15,036.50**
IV. Mileage	
Minimum mileage (not recorded during all trips) was 6,654 (amphibian study), 6,706 (bird study), and 4,600 (mammal study)	
Total mileage = 17,960 miles @ $0.34/mile)	**$6,106.40**
Total matching funds (from PSU and volunteers)	**$179,853.08**

Comments regarding matching funds

The official records indicated that Nathan Lichti was not supported during the 2002 to 2003 academic year. This is in error, and somewhere in the PSU records his employment as a teaching assistant was dropped. I assure the USFWS that he was continuously employed by PSU as a teaching assistant for the three academic years, 2001-2002, 2002-2003, and 2003-2004.

Summary and Conclusions:

Few cities retain natural P&GSs, and among those that do, Portland ranks among the best of examples of what is possible. We utilized this resource and conducted a comprehensive study of biotic diversity in an urban landscape, and have produced an extremely valuable data set that is relatively unique. Our **first objective**, to quantify the distribution of vertebrates in Portland's P&GSs, was completed successfully. We have filled a major gap in our knowledge of the distribution and abundance of terrestrial vertebrate taxa that allows us to establish baseline conditions for the city to which future studies can compare. Moreover, our simultaneous examination of animal and plant distributions, and equal sampling of three animals classes is noteworthy because it allows us to generalize more broadly than most studies.

Our surveys of the bird communities are probably most complete because of the high visibility of birds, and our results indicate that most P&GSs support breeding populations of between 15 and 20 native species. Accurate samples of amphibian communities are far more difficult to obtain because amphibian activity is sporadic and highly dependent upon weather. Dry weather greatly depresses amphibian activity and given that we experienced relatively dry conditions during some of our sampling periods, we may have underestimated amphibian abundance. We nonetheless documented that most amphibian taxa found in surrounding undeveloped areas still retain a presence in the P&GSs. Mammal surveys are likewise difficult to conduct because capture success for different species is dependent on the use of specialized trapping methods. For instance, bats can only be surveyed accurately using combinations of mist netting and auditory surveys, while insectivores (shrews and moles) are generally not attracted to Sherman traps. Furthermore, the wide range of body size among mammals limited our sampling to smaller species. Despite these shortcomings, we established that Portland's P&GSs contain relatively intact communities of small mammals, a major accomplishment for any major metropolitan area.

Our **second objective** was to attempt to identify conditions that promote maintenance of intact native vertebrate communities, and in this regard we believe that we also achieved success. While much still remains to be learned, we believe that our results allow us to draw **several important conclusions**.

The **most important conclusion** is that the retention of large P&GSs (> 10 ha) should be an objective for future planners. Lichti's results showed a positive association between P&GS area and both native tree species richness and native mammal species richness. As a complementary result, the tree and mammal studies showed that non-native species declined sharply as P&GS area increased. Additional analyses that I have conducted (Table 1) demonstrated a strong tendency for the probability of occurrence for most small mammal to increase once P&GSs reached a size of roughly 10 ha. The positive regression coefficients between park area ($\log_{10}$ transformed) and probability of occurrence (significant [$P < 0.05$] or nearly so for 6 of 8 species) clearly demonstrated the benefit of retention of P&GSs in the range of 10 ha.

Table 1. Results of the analyses of probability of occurrence of native mammal species and P&GS area for sites located within Portland's urban growth boundary.

Species[b]	regression[a] coefficient (*P*)	Number(proportion) of sites occupied < 10 ha (n = 6)	> 10 ha (n = 19)
Shorttail weasel	2.96 (0.000)	0 (0.000)	7 (0.368)
Oregon vole	0.37 (0.024)	0 (0.000)	5 (0.263)
N. flying squirrel	1.00 (0.132)	0 (0.000)	7 (0.368)
Shrew-mole	0.90 (0.150)	0 (0.000)	7 (0.368)
White-footed mouse	-------------	6 (1.000)	19 (1.000)
Trowbridge's shrew	2.29 (0.028)	1 (0.167)	13 (0.684)
Vagrant shrew	1.19 (0.070)	1 (0.167)	8 (0.421)
Douglas squirrel	2.00 (0.027)	3 (0.500)	16 (0.842)
Western gray squirrel	-------------	0 (0.000)	1 (0.053)
Townsend chipmunk	2.71 (0.014)	2 (0.333)	17 (0.895)

[a] The regression coefficient from the logistic regression relating probability of occurrence to area of the P&GS. Number in parentheses is the associated *P* value.

[b] Scientific names of species from top to bottom are: *Mustela erminea, Microtus oregoni, Glaucomys sabrinus, Neurotrichus gibbsi, Peromyscus maniculatus, Sorex trowbridgei, S. vagrans, Tamiasciurus douglasi, Sciurus griseus, Tamias townsendii.* White-footed mice and western gray squirrels were not included in the analyses because the former was found at all sites, while the latter was detected at only one location.

Similarly, the preliminary (but robust) analyses of birds demonstrated that the highest species richness was found in P&GSs that were roughly 10 ha in size. The peak richness at this park size was the result of a significant tendency for resident, early successional species of birds to increase in richness between 1 and 10 ha, and then decline with area above roughly 20 ha. The latter decline is probably a consequence of the loss of early successional habitat in larger and older P&GSs. On the other hand, the richness of long-distance Neotropical migrant increased consistently with area. Migrants thus responded positively to any increase in P&GS area, which is important because many Neotropical migrants have experienced declines in abundance in recent decades. Amphibian richness responded less obviously to area than either birds or mammals, but after accounting for effects of habitat and elevation, amphibian species richness also demonstrated a significant positive association with P&GS area. P&GS area covaried with many other variables and therefore it is unclear why area and richness are related, but as a management goal, we can state that conserving large sites ($\geq$ 10 ha) of existing forests should be a very high priority.

A **second important conclusion** is that mammal species richness (and we suspect avian species richness) was affected by conditions in the surrounding landscape matrix. Land use in the 1 km buffer surrounding all P&GSs was classified into 1 of 8 categories, and an increased representation of trees in the buffer was associated with increased native plant species richness and native mammal richness. Thus, small areas of tree cover that alone may not support sizeable native communities of plants or vertebrates can contribute to overall landscape species richness if they are located in close proximity to larger sites. P&GS isolation is reduced by increased tree cover in the buffer. Tree cover need not necessarily be restricted to undeveloped sites: our work showed that developed canopy (i.e., residential areas with substantial tree cover) in the buffer contributed to richness within the adjacent P&GS. We therefore also advise that landowners be encouraged to plant or maintain native tree species to promote positive conditions for the movement of species across landscapes.

Our **third conclusion** is that sites with special geomorphic features, including wetlands or sites with high topographic diversity, should be viewed as priority sites for conservation. Native mammal richness increased with wetland area and amphibian richness declined with elevation. The latter appears to have been driven by the existence of wetland areas in low-lying P&GSs. On the other hand, native herbaceous plant species richness increased with topographic complexity, probably because of the existence of a wider range of ecological conditions on slopes to which different plant species are adapted. These contrasting results between the vertebrates and plants highlights another important message, and that is that managers need to be aware of the specific edaphic (i.e., soil) and habitat needs of different species. This conclusion complicates management issues but it must be recognized: no single management plan is likely to cover all taxa of concern.

Our **final conclusion**, which follows from the last, is that structural features of vegetation are likely to be important for many animal taxa. Appropriate microhabitats are created by understory vegetation and amphibians responded positively to the density of shrubs in the range of 2 to 3 m in height. The native mammalian insectivores also responded positively to microhabitat features, primarily the volume of coarse woody debris and deep organic layers on the forest floor. Although only preliminary, our data show also that birds were highly responsive to understory shrub vegetation, probably because shrubs provide both foraging and nesting sites. High shrub density and thick organic layers in the soil are more likely to be found in large P&GSs, but active management to promote such features at smaller P&GSs are likely to improve conditions for vertebrates.

In summary, all of our recommendations fall in line and are consistent with conclusions that have a strong theoretical basis. Our results are also consistent with studies that have been conducted on larger geographic scales in nonurbanized environments. The important contribution of our work is that our rigorously collected empirical data come from a relatively small geographic area in a poorly studied environment that is inevitably going to increase in area in the near future. Lessons learned from natural habitats appear to apply equally well to the anthropogenically dominated world, and managers can argue convincingly for the retention of habitats of known qualities as cities continue their spread across the landscape.

Supplemental Information:

As supplemental information I provide copies of Lichti's and Roberts' theses. These are valuable documents because they include not only descriptions of the authors analyses and conclusions, but all original data that were the basis for their work. These should be made widely available to provide baseline information on vertebrate and plant distributions for future researchers.