Final Report to the National Park Service Heartland Network

Interactions between Heartland National Parks and Surrounding Land Use Change: Development of Conceptual Models and Indicators for Monitoring

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30 August 2003

Summary

The Heartland Network of national parks initiated this study to develop a land use change segment within its Inventory and Monitoring program. The objectives were to:
1) characterize the current landscape surrounding Heartland parks and summarize patterns of land use change over time, 2) develop conceptual models showing linkages between ecological functioning within parks and land use change, and 3) identify indicators and evaluate methods for monitoring landscape changes in the future.

We included BUFF, CUVA, HEHO, HOSP, LIBO, OZAR, and PERI in this analysis because these parks indicated that land use change monitoring was a top priority. We focused on the impacts of urbanization (including residential, commericial, and industrial development) on park ecosystems, because parks specified this as their most important land use change concern. Current landscapes surrounding parks within the Heartland region are very diverse. HOSP, BUFF, and OZAR are relatively rural, dominated by natural land cover, low housing densities, and good water quality, whereas HEHO, LIBO, CUVA, and PERI have higher housing densities, more agricultural land, and higher rates of water pollution. We considered these similarities and differences between parks when discussing the linkages between ecological functioning and land use activities.

Parks within the Heartland Network experienced large changes in land use activities over the past fifty years. On average, counties within the HTLN gained 43 people/mi² (17 people/km²) and 49 houses/mi² (20 houses/km²). The landscape surrounding PERI experienced the greatest relative increase in population (159%), while OZAR and CUVA experienced the smallest relative increases (11% and 22% respectively). There was a 300% increase in the number of dams within watersheds of the Heartland region, with 146 dams constructed for urban-related uses. On average, counties within the Heartland region lost 30% of their farmland; CUVA (-61%) and HOSP (-51%) experienced the greatest declines, while HEHO (-14%) and OZAR (-18%) experienced the smallest declines.

The specific disturbances related to urbanization which may influence ecological functioning within Heartland parks include the conversion of remnant habitats, water pollution, disruption of hydrologic flow regimes, and the impacts associated directly with increased human population density. Five general mechanisms link these disturbances with ecological functioning. First, land use activities may reduce the functional size of a reserve, eliminating important ecosystem components. Second, land use activities may alter the flow of energy or materials across the landscape, disrupting the ecological processes dependent upon those flows. Third, habitat conversion outside the reserve may eliminate unique habitats, such as seasonal habitats and migration corridors. Fourth, the negative influences of land use activities may extend into the reserve and create edge effects. Lastly, increased population density may directly impact parks through increased recreation and human disturbance. We developed the conceptual models based on these mechanisms, and discussed the possible ecological consequences for different groups of Heartland parks. Additionally, because parks differ in surrounding landscape characteristics and management priorities, we discussed the most significant linkages between land use change and ecological functioning for individual parks.

Lastly, we suggested landscape-level demographic and ecological indicators associated with these linkages for monitoring change in the future, and discussed metrics, methods, and analysis which may be incorporated into a long-term land use change monitoring plan.

Table of Contents

List of Tables

List of Figures

Introduction

One of the goals of the National Park Service (NPS) Inventory and Monitoring (I & M) program is to initiate long-term monitoring of natural resources within its parks. Because surrounding land use activities can significantly influence the status of natural resources within parks, it is important to consider the impacts of land use change in any monitoring program. To determine indicators of land use change which can be monitored over time and which will contribute to the detection of long-term trends, it is necessary to understand key linkages between surrounding land use activities and ecosystem functioning within parks. The Heartland Network (HTLN) of National Parks initiated this study to develop a land use change segment within its I& M program. The objectives were to:

1) **Characterize the current landscape surrounding Heartland parks and summarize patterns in land use change over time.**
2) **Develop conceptual models showing linkages between ecological functioning within parks and land use change in surrounding areas.**
3) **Identify indicators and evaluate methods for monitoring landscape changes.**

We began by analyzing recent and historical (1950 to present) datasets to quantify landscape characteristics and land use change around parks. We then focused on land use change issues relevant to Heartland parks when creating the conceptual models. Conceptual models were based on general ecological mechanisms linking surrounding land use changes and ecological functioning within natural areas. To consider regional patterns within the Heartland Network, we grouped parks that shared similar landscape and ecosystem characteristics, and evaluated the importance of certain ecological linkages for each group. Additionally, we discussed the most significant future land use change concerns for each park, considering current landscape setting, land use change trends, and important ecosystem components. We concluded by suggesting possible indicators of land use change, and discussing methods and protocols which can be used in the implementation of a long-term monitoring program.

Background

Nature reserves are important for the conservation of biodiversity because they preserve natural habitats, and provide a refuge where ecological processes can persist in the absence of large-scale human disturbance. However, ecological processes, such as energy flows and organism movements, often function on a landscape level without regard for the ecologically arbitrary political boundaries that usually delineate reserves (Wilcove and May 1986, Newmark 1985). Consequently, the persistence of ecological functioning inside reserves often depends upon the maintenance of the physical and biological attributes of natural systems located outside of reserve boundaries.

Land use activities may threaten ecological functioning within reserves by modifying those attributes (Janzen 1986). For example, water pollution originating from an industrial plant may impair aquatic ecosystems in a reserve downstream, or land conversion outside of reserve boundaries may create edge effects for populations inside the reserve. Historically, reserves have generally been located in isolated, rural areas dominated by low-intensity land use activities, so concerns about the detrimental consequences of land use practices have been relatively limited. However, in recent decades humans have been transforming these formerly natural and semi-natural agricultural landscapes (e.g. cropland, pasture, managed forest) into landscapes with increasingly urban characteristics. This conversion to human-created landscapes is causing concern among reserve managers, as they realize the potential negative consequences for ecological functioning within reserves.

The NPS has a strong interest in protecting ecosystems and processes within park boundaries, as they work to ensure the integrity of natural systems for future generations. In fact, many national parks have identified either actual or possible future negative impacts of land use change; in a survey of 303 park managers nationwide, urban encroachment was named as the biggest external threat to park natural resources (U.S. General Accounting Office (USGAO) 1994). The HTLN, consisting of ten parks in five Midwestern states, is no exception to this trend of national concern. Seven parks in the network identified "surrounding land use change" as one of their top five natural resource concerns, and would like to monitor, and possibly mitigate, both the causes and ecological consequences of these changes in the future.

In order to successfully monitor and mitigate the negative consequences of land use activities, park managers first need to understand how these activities may be disrupting ecological processes within parks. Five general ecological mechanisms have been identified which link land use change outside of nature reserves with ecological functioning within reserves (from Hansen and Rotella 2001, Hansen and DeFries in prep; Table 1). First, land use activities may reduce the functional size of a reserve (the functional size includes the reserve and surrounding intact ecosystems). Change outside of reserves may alter or eliminate important ecosystem components and diminish the spatial scale of the ecosystem, rendering properties within the reserve unable to function on that smaller scale. Second, land use activities may alter the flow of energy or materials across the landscape, and disrupt the ecological processes dependent upon the movement of those flows into and out of the reserve. Third, the conversion of natural areas outside of reserves may eliminate unique habitats, such as seasonal habitats and migration corridors, upon which organisms depend for certain life history requirements. Fourth, the negative influences of land use activities may extend into the reserve and create edge effects for periphery reserve ecosystems. Lastly, increased population density may directly impact park resources through increased recreation and human disturbance. By understanding how these mechanisms are at play in National Parks, we can more efficiently monitor the causes and consequences of land use change in the future.

Many aspects of this general conceptual approach to understanding the ecological consequences of land use change apply to the HTLN. Although the land and water surrounding midwestern parks have been influenced by human activities for centuries, ecosystems within parks have adapted to rural surroundings, and depend on the maintenance of ecological processes moving across this semi-natural landscape. The general ecological mechanisms described above will contribute to the development of indicators and future monitoring programs, and help to understand and possibly mitigate any current or future ecological consequences of land use change.

The Heartland Network

Managers of seven of the ten Heartland Network parks indicated that land use change was one of their top five natural resource concerns; we included these seven parks in the landscape level analysis and development of the conceptual models (Table 2). Although these parks span five states (Arkansas, Missouri, Ohio, Indiana, and Iowa), they are similar in that they share common ecosystem characteristics influenced by both eastern deciduous forest and prairie biomes. However, parks differ greatly in size, ranging from 186 ac (75 ha) for Herbert Hoover National Historic Site, to 95,730 ac (38,757ha) for Buffalo National River. Because of these similarities and differences, along with differences in surrounding landscape characteristics, we took into consideration the broad patterns of land use change within the HTLN, as well as local and regional patterns of change.

Methods

To create conceptual models demonstrating the possible ecological consequences of land use change and develop monitoring indicators, we took the following steps:

1) Identified general land use change concerns (i.e. drivers) and dominant ecosystems for each park, then grouped parks based on shared ecological linkages with land use change.
2) Characterized both the current landscape setting and land use change trends to identify the most important linkages.
3) Created conceptual models demonstrating the ecological linkages that are important for each group of parks and possible consequences for ecological functioning.
4) Identified potential indicators and methods for monitoring land use change in the future.

Identifying Land Use Change Concerns and Dominant Park Ecosystems

Possible land use changes occurring within the HTLN include residential and commercial development, agricultural expansion or decline, deforestation and reforestation, mining, and industrialization. However, for the landscape analysis and conceptual models we wanted to include only the land use change trends that were relevant to these seven parks. Therefore, we consulted the HTLN Phase I Draft Monitoring Plan (NPS 2002) to identify local and regional park land use change concerns recognized in the Land Use Change Theme section. We also considered land use change trends surrounding other parks (Hansen and Rotella 2001, Ambrose and Bratton 1990, USGAO 1994), and rural areas of the United States in general (Brown et al. in press), in order to reinforce the concerns of Heartland parks and consider other possibly important land use changes. We then focused on the resulting relevant land use changes for grouping the parks, and included these changes as 'drivers' in the conceptual models.

To characterize dominant ecosystems for each of the seven parks, we again consulted the Draft Monitoring Plan (NPS 2002) and specific park summaries, land cover maps from the U.S. Geological Survey (USGS) of the parks and surrounding areas, and other relevant regional publications, such as the Ozark-Ouachita Highlands Assessment compiled by the United States Forest Service (USFS; U.S. Department of Agriculture (USDA) 1999).

Functional Grouping of Parks

The main differences between these seven parks that influence linkages between ecological functioning and land use activities were dominant park ecosystem type and extent of surrounding natural habitat. We focused on these attributes because they have the potential to greatly influence both ecological functioning within parks and the magnitude of the linkages with surrounding land use change. Based on these factors, we created two different grouping methods for discussing different land use change drivers within the conceptual model.

We expected the magnitude of linkages between habitat conversion and park ecological functioning to be heavily influenced by the extent of surrounding natural habitat to which park ecosystems may be connected. Additionally, we expected the relative impact of human disturbance to be influenced by the state of human activity already present in the landscape. Therefore, we created two groups of parks based on characteristics of the dominant surrounding land cover and land use: BUFF, OZAR, and HOSP are all surrounded by relatively dense and contiguous forest (Figure 1b), whereas the landscapes around PERI, LIBO, HEHO, and CUVA are dominated by agriculture and fragmented forest (Figure 1a). For the conceptual model we discussed the ecological consequences of habitat conversion as they apply to these groups, calling the first group "forest parks" and the second group "agricultural parks".

For considering all other land use change drivers (i.e. related to the flow of water through the park), we created two groups of parks based on the dominant park ecosystem type: BUFF (Buffalo River), CUVA (Cuyahoga River), and OZAR (Jack's Fork and Current Rivers) are all river-based parks, whereas HOSP, PERI, HEHO, and LIBO are all largely terrestrial parks. We called the first group "river parks" and the second group "land parks", and discussed this aspect of the conceptual model based on the characteristics of each group.

Additionally, we often summarized patterns for the HTLN as a whole. In these analyses, we summed data from either the counties or watersheds within all park study areas, and reported averages and extremes for the region.

Characterization of Current Landscape and Change Over Time

To quantify the landscape setting of parks, and to determine relevant land use change issues for the conceptual model discussion, we summarized landscape characteristics for the region surrounding parks. We defined the region of importance for each park as the area directly surrounding the park that may influence ecological functioning. However, the delineation of the area of influence was also dictated by the availability of data. Most datasets were organized at either the watershed or county level, so the region of influence surrounding parks was slightly different for these two different spatial scales. We defined the area of influence for data organized at the watershed level as the watershed that the park falls into, plus all adjacent watersheds. For data organized at the county level, we defined the area of influence differently for land and river parks. For river parks, we included all counties that fell within the park's watershed boundary. For land parks, we did not use the watershed as the basis for the area of influence because 1) terrestrial processes seem to be more important for these parks than watershed processes (NPS 2002), and 2) land parks were often located on the edge of the watershed rather than the center, so that the distribution of counties that fell within the watershed boundary was skewed to either one side of the park or the other. To ensure that the area of evaluation was more evenly distributed around the park, we instead created a twenty mile buffer around the park, and included all counties that fell within this buffer. See Table 4 for a complete list of all counties and watersheds included in analysis.

We focused on landscape level spatial datasets that quantified or represented land use changes related to urbanization (see Table 3). County level data included U.S. Census Bureau (USCB) data such as housing and population density, as well as National Pollutant Discharge Elimination System (NPDES) water discharge permit records from the Environmental Protection Agency (EPA) used as an index for industrial activity. Water related data was organized at the level of the USGS Hydrologic Cataloging Unit (hereafter referred to as 'watershed'), and included datasets describing conventional water pollution and the extent of hydrologic modification caused by dams. To evaluate current land cover around parks, we used the USGS National Land Cover Dataset with a resolution of 30 meters. We also considered the importance of proximity to cities when characterizing the current landscape.

We evaluated recent patterns of land use change using spatial datasets from the years 1950 to 2000 because this is the time period where land use change trends are relevant to changes still occurring today. Also, important datasets exist reliably and consistently for this time period. Datasets at the county level included population and housing surveys from USCB, and farmland acreage statistics from the U. S. Census of Agriculture (see Table 3). Additionally, we looked at the number of major dams built over that time period for purposes related to urbanization, including water supply, flood control, hydroelectricity, and recreation.

Development of Conceptual Models

In creating the conceptual models, we incorporated the relevant land use change issues and ecosystem components determined to be important for Heartland parks. We determined important ecological linkages and mechanisms based in part on the possible ecological consequences recognized by parks in the HTLN Draft Monitoring Plan (NPS 2002). Additionally, we consulted the ecosystem conceptual models created by other scientists for the HTLN, species and community inventory lists from individual parks, land cover maps, and personal knowledge gained from park visits to also include those linkages that may be important based on ecological theory.

Individual Park Visits and Data Gathering

In the winter of 2003, we visited several of the Heartland parks to familiarize ourselves with regional landscape setting, local land use concerns, and dominant ecosystem components and processes. We toured BUFF, HOSP, PERI, and OZAR, in addition to other Heartland parks not included in this land use change analysis. Additionally, while attending regional park meetings, we spoke with personnel from HEHO and CUVA. These visits and conversations contributed to all aspects of the methods described above, especially for identifying relevant ecological linkages between land use change and ecosystem functioning, reinforcing important local and regional land use change concerns, and characterizing the current landscape setting.

Development of Indicators

We identified potential indicators of land use change for monitoring long-term trends in the future. These indicators were attributes of the landscape that measure changes in land use and ecological functioning, taking into consideration the potential impacts of edge effects, decreased ecosystem functional size, loss of unique habitats, alteration of ecological flows, and increased human disturbance. Also, to ensure the detection of patterns and scientific applicability in the long-term monitoring process, the recommended indicators were sensitive to critical changes in the landscape, could be assessed over a wide range of conditions, could be accurately and precisely estimated, and provided results that could be easily interpreted and explained. Finally, to ensure that the indicators would be relevant to park management goals, selection was guided by parks' resource management issues and concerns, as well as the budget constraints of the I & M program.

Results and Discussion: Landscape Characterization and Change

Although these seven Heartland parks span a broad geographic region and are influenced by different natural, social, and economic landscapes, all specified urban encroachment as the most significant land use change issue. These concerns resound throughout the NPS (USGAO 1994), and are consistent with national land use change trends that show populations of formerly rural counties growing at high rates throughout much of the U. S. (Brown et al. in press). In order to place Heartland parks into a realistic landscape setting and focus on relevant ecological issues for the conceptual model discussion, we used various spatial datasets (see Table 3 for summaries and sources) which measure aspects of residential, commercial, and industrial development to characterize the current and changing landscapes around parks.

Current Land Cover

All parks are located within the eastern deciduous forest biome except PERI which, although largely forested, sits on the edge of the prairie/forest ecotone, and HEHO which is located in the heart of the Great Plains. Dominant land cover categories included urban (industrial lands, low and high intensity urban, and bare ground), natural (forest, shrub, and wetlands), and agricultural areas (row crops and pasture/hay) (Figure 1). Early-1990's land cover within the HTLN can be characterized as a continuum based on the degree of human settlement, ranging from largely agricultural to largely natural. We summarized the relative proportion of land cover types surrounding each park (using the county-defined study areas) based on the number of 30 meter pixels within a cover type compared to the total number of pixels (Table 5, Figure 2). The HEHO landscape is dominated by agricultural cropland and scattered pasture (82% of land cover); LIBO is characterized largely by mosaics of cropland and pasture (64%), with some remaining natural forest (32%); PERI is equally surrounded by pasture (47%) and remnant forest tracts (51%); and OZAR, HOSP, and BUFF are surrounded largely by natural forest (67 to 86% of land cover). USFS National Forest (NF) land is a significant component of the landscape for these last three forest parks, with Mark Twain NF in close proximity to OZAR, Ozark NF forming a boundary with parts of BUFF, and Ouachita NF spreading northwest of HOSP. Most of the Heartland parks are relatively isolated from large metropolitan areas, so that urban areas do not constitute a significant proportion of the surrounding land cover (5% or less for six of the seven parks). The exception is CUVA, which is located between the Cleveland and Akron metropolitan areas; higher density urban and industrial areas are a more significant component of the surrounding landscape (21% of land cover).

Locations of Cities

We evaluated only cities within the HTLN that have a population greater than 1000 people. Generally, the landscapes surrounding Heartland parks (using the county-defined study areas) are not dominated by the presence of large cities. Most (approximately 58%) of the cities in close proximity to Heartland parks are small, having less than 5,000 residents. The majority of the rest of the cities (approx. 26% of total) have less than 50,000 people. The remaining largest cities (>50,000 people) are located near PERI, LIBO, CUVA, and HEHO, with most of those associated with the Cleveland-Akron metropolitan area near CUVA.

Current Population and Housing Densities

Within the landscapes surrounding Heartland parks (using the county-defined study areas), OZAR has the lowest population density with 23 people per square mile (9 people per square kilometer), and CUVA has the highest with 980 people/mi^2 (378 people/km^2) (Table 6). The five other parks range from 35 to 106 people/mi^2 (14 to 41/km^2). Overall patterns within the HTLN reflect patterns around parks, ranging from very rural with low human population densities to very urban with high population densities (Figure 3). The 52 counties in the region (see Table 4) have on average 167 people/mi^2 (64 people/km^2); if counties around CUVA are not included in the average, population density drops to 61 people/mi^2 (23 people/km^2). Reynolds and Shannon counties (of OZAR) in Missouri have the lowest population density with 8 people/mi^2 (3 people/km^2), whereas Cuyahoga County (of CUVA) in Ohio has the highest with 3020 people/mi^2 (1166 people/km^2). Ten of the 52 counties (19%) have less than 20 people/mi^2 (8 people/km^2), whereas 23 counties (44%; including all 6 counties for CUVA) have more than 50 people/mi^2 (19 people/km^2).

Not surprisingly, patterns in housing density are similar to those for population density. For parks, OZAR again has the lowest density with 11 houses/mi^2 (4 houses/km^2), and CUVA the highest with 418 houses/mi^2 (167 houses/km^2; Figure 4, Table 6). The remaining five parks ranged between 15 and 44 houses/mi^2 (6 and 18 houses/km²). The average housing density for all counties in the HTLN is 72 houses/mi² (27 houses/km²); if CUVA is not included, the average falls to 26 houses/mi² (10 houses/km²). Shannon (MO) and Cuyahoga (OH) counties again have the minimum and maximum densities, with 4 houses/mi² (2 houses/km²) and 1336 houses/mi² (516 houses/km²) respectively. Almost a quarter of the counties (23%) have fewer than 10 houses/mi² (4 houses/km²), and 50% have fewer than 20 (8 houses/km²). Eight of the 52 counties (including the 6 counties surrounding CUVA) have greater than 80 houses/mi² (31 houses/km²).

Current Industrial Activity

We used the number of industrial discharge permits within each county as a measure of industrial activity (Figure 5). Within the HTLN as a whole, densities of industrial sites are relatively low, with only one discharge site every 49 mi² (130 km²). Sixty percent of all counties (31 of 52) have fewer than 10 industrial sites in the entire county; most of those low density counties are located in Arkansas and Iowa. For landscapes surrounding individual parks, LIBO and CUVA have the most industrial sites (one per 17 mi²/ 44 km² and 20 mi²/ 52 km², respectively) and BUFF and HOSP have the least (one per 874 mi²/2272 km² and 211 mi²/ 549 km², respectively) (Table 6).

Water Quality—Conventional Pollutants

Conventional pollutants include those non-toxic pollutants discharged in wastewater by industry and municipal sources. The EPA focused on four main pollutants when creating indices of water quality: ammonia, dissolved oxygen, phosphorus, and pH. We summarized water quality within the HTLN based on this index, which quantified the total amounts of conventional pollutants discharged over an average one-year period (calculated from 1990-1997 data). The severity of pollution within the watershed was measured as the percent of time that samples exceed permitted limits; better water quality = samples exceed limits less than 10% of the time, moderate water quality problems = 11-25% of the time, and severe water quality problems = >25% of the time.

Watersheds within the HTLN as a whole generally have moderate numbers of incidences where permitted limits are exceeded (Figure 6), with 23 watersheds (48%) exceeding limits 11-25% of the time. Fourteen watersheds (25%) exceed pollution limits fewer than 10% of the time, while 5 watersheds (10%) have severe pollution problems, exceeding limits more than 25% of the time; most of these severely polluted watersheds are concentrated around CUVA and LIBO. The remaining six watersheds did not have sufficient data to be included in the summary. The watersheds with the greatest pollution problems are located in Ohio, Iowa, and northwest Arkansas, and surrounded PERI, CUVA, and HEHO.

For considering water quality of landscapes surrounding individual parks, we averaged the scores (1 for better water quality, 2 for moderate, and 3 for severe) of the park watershed and all surrounding watersheds. OZAR has the best water quality, with an average watershed score of 1.2, and CUVA, HEHO, and PERI the worst, with average scores of 2.3, 2.3, and 2.1 respectively (Figure 13, Table 6). When including only the watersheds within which parks are actually located, water quality is generally good. Most of the parks have minimal levels of pollution; only CUVA has severe problems with high levels of conventional pollutants (Figure 6).

Degree of Hydrologic Modification

This index created by the EPA describes the degree of hydrologic modification by quantifying the volume of water that reservoirs are capable of impounding within that watershed. Watersheds within the HTLN have relatively high degrees of hydrologic modification by dams (Figure 7). Only eight of the 48 watersheds (17%) have low capacities to impound water, whereas 40 have medium and high capacities (20 watersheds in each category). Many of those high capacity watersheds are concentrated in Arkansas, although medium and high capacity watersheds are generally spread throughout the entire region. We summarized degree of hydrologic modification for individual parks in the same way as we did for conventional water pollution, by averaging the EPA scores, with 1 being low modification and 3 being high modification. Most parks have relatively high degrees of hydrologic modification (average score above 2), with HOSP having the highest average score (2.8), and HEHO and OZAR the lowest (1.7 and 1.8 respectively) (Figure 13, Table 6).

Population Change, 1950-2000

The HTLN overall experienced large population increases over the past fifty years (Figure 8). The average population increase for all counties was 65%, ranging from a 34% decrease in Clay County, Arkansas to a 303% increase in Benton County, Arkansas. Only seven of the 52 counties (13%) experienced a decrease in population, with most of those counties located in southern Missouri and northern Arkansas. Fifteen counties (29%) experienced 50-200% population growth, and six recorded greater than 200% growth. Additionally, we summarized increases in population densities within the HTLN. Relative trends are the same as for general population growth, but summarizing increases in density provide a more realistic picture of the magnitude of change. On average, counties gained 43 people/mi^2 (17 people/km^2). Again, Clay County declined in population density the most, losing 14 people/mi^2 (5 people/km^2) and Benton County increased the most, gaining 136 people/mi^2 (53 people/km^2). Thirty-five percent of counties gained more than 25 people/mi^2 (10 people/km^2).

Similar to county patterns, landscapes surrounding individual parks experienced overall population growth during the past fifty years (Table 7, Figure 9). PERI experienced the greatest increases in population (159%), while OZAR and CUVA experienced the smallest increases (11% and 22% respectively). Although CUVA experienced one of the lowest relative increases in population, it experienced the greatest increase in density, gaining 179 people/mi^2 (72 people/km^2). Again, OZAR experienced the smallest increase in density, gaining only 2 people/mi^2 (1 person/km^2).

Change in Housing Densities, 1950-2000

Although housing growth within the HTLN mirrored patterns observed for population, relative changes in housing were much larger. Counties within the region experienced an average 497% increase in number of houses, with Cedar County, IA experiencing the smallest increase (97%), and Saline County, AR experiencing the greatest (1586%). On average, counties gained 49 houses/mi^2 (18 houses/km^2); however, most counties (33 of 52; 63%) gained fewer than 20 houses/mi² (8 houses/km²). Housing growth varied greatly around parks, with BUFF and HOSP experiencing the largest relative increases (746% and 745% respectively) and CUVA experiencing the smallest (173%; Table 7). Although CUVA experienced the lowest rate of housing growth, it recorded the greatest increase in absolute housing density, gaining 262 houses/mi² (101 houses/km²). OZAR gained the fewest houses, at 9/mi² (3 houses/km²), but had very high rates of growth (442%).

Trends in Major Dam Construction, 1950-1996

From 1950 to 1996, there was a 315% increase in the number of dams within watersheds of the HTLN, with 148 dams constructed overall for urban-related uses (i.e. recreation, water supply, flood control, and hydroelectricity; Figure 10). Each park gained on average 21 dams in the surrounding watersheds during those forty-six years, with HOSP gaining the most (51 dams) and HEHO gaining the fewest (only 2 dams).

Change in Farmland Acreage, 1950-1997

A large portion of agricultural lands in the HTLN went out of production during the past fifty years. Only two counties gained farmland, while the remaining 50 counties all lost farmland acreage (Figure 11). On average, counties lost 30% of their farmland; the largest gain was +1.3% in Clay County, AR, while the largest loss was -92% in Cuyahoga County, OH. Most counties (27 of 52; 52%) lost 20 to 50 percent of their farmland acreage, while eight counties lost more than 50%. All individual parks experienced declines in surrounding farmland acreage as well (Table 7, Figure 12). CUVA (-61%) and HOSP (-51%) experienced the greatest declines, while HEHO (-14%) andOZAR (-18%) experienced the smallest declines. This indicates a significant shift in land use within a region that has historically been dominated by agricultural activities. This also indicates that more private lands have become available for urban development, because former farmlands are often prime locations for residential areas.

Summary of Current Landscape Characteristics

The current landscape of the HTLN is very diverse, ranging from areas of dense contiguous forest to areas largely dominated by agriculture, and relatively rural areas to very urban. Differences in landscape characteristics between parks reflect this diversity, with parks falling along a gradient ranging from relatively isolated to more heavily influenced by human activities. The landscapes surrounding HOSP, BUFF, and OZAR are relatively undisturbed, dominated by natural land cover types (Figure 2), low housing densities (Figure 4), and good water quality (Figure 13), whereas HEHO, LIBO, CUVA, and PERI have higher housing densities (Figure 4), lower proportions of natural land cover (Figure 2), and higher rates of water pollution (Figure 13). Furthermore, OZAR and HEHO have the lowest degree of hydrologic modification, while the remaining parks experience relatively high levels of modification by dams (Figure 13). It is important to consider these similarities and differences when discussing the linkages between ecological functioning and land use activities, as landscape characteristics will greatly influence the strength of these linkages.

Results and Discussion: Conceptual Model

Although land use change is occurring at different scales for each of the parks, the concerns about the potential ecological consequences are similar. In general, all of the park managers recognize the possible consequences of urbanization on water quality, with river-based parks specifically concerned about the ecological effects of nutrient loading and sedimentation on functioning within aquatic systems. Almost all of the park managers also recognize the role that urbanization plays in the introduction of exotic species into reserves, with consequences for the functioning and persistence of native plant communities. Additionally, terrestrial park managers (LIBO, PERI, and HEHO) generally acknowledge the potential ecological consequences of habitat loss associated with urbanization. These park concerns correspond well with the general ecological mechanisms addressed in the conceptual model, which reinforces the appropriateness of using this method for evaluating the consequences of land use change within the HTLN.

The specific drivers of ecological change associated with residential, commercial, and industrial development around Heartland parks include the conversion of remnant habitats, water pollution, disruption of hydrologic flow regimes, and the impacts associated directly with increased human population density around parks (Figure 14). In determining the relevant ecological mechanisms associated with these drivers, we considered only the ecosystem components still intact in parks today that might be linked with surrounding landscapes. Because Heartland parks are surrounded by lands that have been influenced by human activities for over a hundred years, the most relevant ecosystem components and processes are those that have adapted to a relatively fragmented landscape. Current land use changes influence functioning within these ecosystems largely by disrupting or changing the characteristics of movements across this patchy landscape. That is why we focused on ecological mechanisms which describe the influences of land use activities on species that use remnant habitats outside of the park, water quality and aquatic systems, species adversely impacted by direct human interactions, and the spread of species adapted to human landscapes (e.g. exotics and opportunistic natives).

CONVERSION OF REMNANT HABITATS

All of the parks are to some degree surrounded by relatively natural lands which may be linked to park ecosystem functioning (Figure 1). Much of this land is privately owned, so is more vulnerable than protected public lands to clearing for urban growth. When the conversion of habitats occurs around parks, it diminishes surrounding natural buffer areas and impedes access to more distant habitats, which could have significant consequences for park ecosystem functioning. These consequences are manifested through ecological mechanisms which decrease the functional size of the park, introduce edge effects, and eliminate unique habitats outside the park.

Decrease Functional Ecosystem Size

The loss of habitat outside of parks can drastically reduce the functional size of park ecosystems. The functional size of the park includes the area of the park plus surrounding lands which contribute to ecosystem functioning. When development converts bordering remnant natural habitats to urban landscapes, the area available for ecosystem processes is diminished, and the remaining habitat may not be sufficient for sustaining certain species and ecosystem components.

Recent increases in housing densities throughout the HTLN (Figure 9) indicate that residential and commercial areas are expanding around parks. The largely forested areas around HOSP, OZAR, and BUFF have experienced a 650% increase in housing density since 1950 (Table 7). The contiguous forest habitats surrounding these parks are a natural extension of park ecosystems, and sustain ecosystem functioning on a level that extends well outside of park borders. Conversion of these forests to urban landscapes will significantly reduce ecosystem size, and greatly influence ecological functioning within parks. Similarly, housing densities in agricultural areas around PERI, LIBO, HEHO, and CUVA have increased more than 350% over the past fifty years (Figure 9, Table 7). Reductions in functional ecosystem size were probably most significant for these parks when eastern deciduous forest and tallgrass prairie habitats were initially converted to agriculture long ago. However, the ecological linkages are still relevant today, as current land use changes are increasingly transforming semi-natural areas to more urban landscapes. Species have adapted to this semi-natural landscape, and the maintenence functional ecosystem size depends upon the preservation of characteristics associated with agricultural lands. However, the ecological consequences associated with reduced ecosystem size are probably less significant for agricultural parks than forest parks; agricultural parks are more isolated from remaining natural areas, and may have already adapted to a smaller functional ecosystem size.

The influence of dam construction on functional ecosystem size may also be an important consideration for parks with a significant aquatic component. The number of dams constructed on waterways that flow into parks has increased over 300% in the past fifty years (Figure 10). Dams may significantly reduce the functional size of aquatic ecosystems by creating barriers that restrict the movement of organisms throughout the watershed.

Reducing the functional ecosystem size of Heartland parks could threaten the persistence of species within parks by either introducing Species-Area effects, or by disrupting certain aspects of the trophic structure of park communities (Figure 15a).

Species-Area Effects

Habitat loss which diminishes the functional size of park ecosystems would result in an overall reduction in the amount and variety of available resources, possibly leading to population declines within the park. Because smaller populations are more likely to suffer extinction (Richter-Dyn and Goel 1972, Leigh 1981, Diamond 1984) due to decreased genetic variation (Wright 1931) and increased risk of chance extinction (MacArthur and Wilson 1967, Rosenzweig 1995), some species may consequently disappear from the park. The loss of species from small habitat fragments is reflected in the species-area relationship, which states that the number of species found in a habitat island is a function of its area, i.e. the larger the island, the more species it can support (MacArthur and Wilson 1967, Preston 1962). This has been demonstrated as a significant phenomenon within bird (Pimm and Askins 1995, Johnson 1975), mammal (Bolger et al. 1997, Gottfried 1979), and fish (Angermeier and Schlosser 1989, Griffiths 1997, Matthews and Robison 1998) populations within North America and globally (Brooks et al. 1999, Brooks et al. 1997, Temple 1981, Pimm et al. 1995), and therefore may be an important consideration when addressing the conversion of terrestrial and aquatic habitats near park borders.

Species-Area effects could have significant implications for species richness in Heartland parks, as populations may depend on bordering natural forest, pasture (i.e. surrogate prairie), and aquatic habitats. All parks seem to have concerns about the persistence of certain populations that could be influenced by Species-Area effects, including forest and prairie communities in general (all parks), threatened and endangered species (BUFF and OZAR), herpetofauna (BUFF, PERI, and HEHO), birds (OZAR), butterflies (HEHO), fish (BUFF and OZAR), and bats (BUFF). Populations that may especially suffer declines and risk extinction when functional ecosystem size is reduced are taxa in which individuals have large home ranges (Lovejoy et al. 1986, Newmark 1995). This may be an important concern for parks with black bear (*Ursus americanus*), elk (*Cervus canadensis*), and raptor populations, as the conversion of forest to urban areas would reduce the amount of habitat area for these species and limit densities to levels below the threshold of viable populations. Additionally, Species-Area effects may have proportionately large negative effects for rare species with relatively small populations (such as endangered bats, herpetofauna, or plants), or species within endangered ecosystems (such as cane breaks, glades, prairies, and caves), that cannot withstand any further declines due to habitat loss outside of the park. Lastly, Species-Area effects may be exacerbated for long-lived taxa with relatively slow rates of population growth, such as certain plants and larger mammals, which may be unable to quickly rebound from initial population declines resulting from habitat loss.

Disrupt Trophic Structure

The reduction of functional ecosystem size may disrupt community trophic structure within park ecosystems. Top level predators often have large home ranges, so are more prone to extinction when habitat conversion renders the remaining habitat area insufficient for supporting viable populations (Lovejoy et al. 1986, Newmark 1995). The trophic structure is consequently altered when organisms lower in the food chain, such as mesopredators (Crooks and Soule 1999, Rogers and Caro 1998) and herbivores (Terborgh et al. 2001, Palomares et al. 1995), are released from competition and predation pressures that previously regulated their populations, and experience an explosion in population numbers.

Ecological consequences which stem from the disruption of trophic structure are probably not extremely significant for most Heartland parks today. Extinctions of most top level predators around Heartland parks, especially carnivores such as cougars, golden eagles, and wolves, occurred long ago with initial land conversions of forest to agriculture, and from predator control measures. Although the ecological consequences of these extirpations are still very evident today, including deer and coyote overpopulation, actual extinctions are probably not significant potential consequences of recent land use changes.

One exception is for the largely forested parks of Arkansas and Missouri in which black bear populations still persist (BUFF, HOSP, OZAR; USDA 1999). Although the extirpation of local bear populations from habitat loss is a significant ecological consequence in itself (see previous section on Species-Area effects), it is difficult to predict the severity of the impacts of extinction on trophic structure, because bears are generally omnivorous, so their influence is spread throughout the food chain. However, black bears have been shown to significantly influence ungulate populations through predation on juveniles (Kunkel and Mech 1994, Bertram and Vivion 2002), so declines in bear populations may indirectly exacerbate white-tailed deer (*Odocoileus virginianus*) overpopulation problems in the region. Raptor populations are another example of top level predators with relatively large home ranges which exist in all Heartland parks. Conversion of forest and agricultural land to urban areas would significantly limit habitat for raptors, including hawks (*Buteo* and *Accipiter* spp.), bald eagle (*Haliaeetus leucocephalus*), Mississippi kite (*Ictinia mississippiensis*), Northern harrier (*Circus cyaneus*), American kestrel (*Falco sparverius*), and owls which depend on these habitats for breeding sites and prey resources. Local extinctions of raptors could release from predation and cause moderate increases in prey populations, such as small mammals.

Introduce Edge Effects

Habitat conversion outside of park boundaries can influence ecosystem functioning by introducing edge effects to the periphery of the park (Figure 15b). Edge effects related to habitat conversion occur when land use activities surrounding parks change the biological and physical characteristics of formerly interior habitat to conditions associated with open edge habitat. This includes changes in the abiotic environment, with edge habitats experiencing increased solar radiation, greater daily temperature extremes, and increased exposure to wind (Saunders et al. 1991, Matlack 1993). Altered microclimate conditions may negatively influence interior species directly by displacing individuals which are physiologically intolerant of hotter and drier edge conditions. This may be a detrimental edge effect for amphibians (deMaynadier and Hunter 1998, Spotila 1972) and small mammals (Getz 1961, Stevens and Husband 1998) with specific forest floor temperature and moisture requirements.

Furthermore, forest conversion will increase the proximity of open habitats, allowing shade intolerant species to invade formerly interior forest remnants, increasing predation, competition, and parasitism pressures for interior species. This has been shown to be especially detrimental for birds (Ambuel and Temple 1983, Gates and Gysel 1978, Paton 1994), small mammals (Matthiae and Stearns 1981, Bolger et al. 1997), plants (Alverson et al. 1988, Matlack 1994, Brothers and Spingarn 1992, Fraver 1994, Ranney et al. 1981), and insects (Lovejoy et al. 1986).

Areas surrounding Heartland parks have gained on average 57 houses per square mile in recent decades (Table 7), indicating that habitat conversion for urban development is occurring on a large scale, and could greatly contribute to edge effects within parks. Increased habitat conversion will exacerbate edge effects that already exist for parks in relatively fragmented regions, as well as introduce edge effects to parks in more undeveloped areas. Agricultural parks (PERI, HEHO, LIBO, CUVA) have been exposed to edge conditions on a large-scale since the original conversions of prairie or forest to agriculture, so current land use changes which increase the amount of edge habitat will probably not create any new significant ecological consequences for these park ecosystems. However, chronic problems related to edge effects caused by these original habitat conversions are still evident for certain components of agricultural park ecosystems today (such as high rates of bird nest predation or parasitism, or increased white-tailed deer herbivory near edges), and recent urban development activities around parks may exacerbate these problems. For parks which are surrounded by relatively contiguous forest (HOSP, BUFF, and OZAR), urban development which creates edge habitats would introduce conditions that these park ecosystems have never before been exposed to on a large scale. Changing the characteristics of these forests would introduce novel biotic and abiotic interactions that may threaten the persistence of native plant, insect, amphibian, and mammal populations.

Edge effects related to habitat conversion are relevant for prairie ecosystems as well as for forests. Negative biotic interactions (e.g. increased predation and parasitism) correlated with the presence of woodland edges have been documented for native prairie populations (Winter et al. 2000, Burger et al. 1994). Urban development around the remnant prairies of HEHO may lead to an increase in the planting of residential forests, creating edge effects within prairie ecosystems due to the close proximity of predators or competitors normally associated with forest.

Eliminate Unique Habitats

The full range of habitats necessary to support all species within park ecosystems usually is not available inside park boundaries (Newmark 1985). This may be especially true for patchy habitats that are not evenly distributed across the landscape, or habitats that have become rare because they are often the first to be developed for human uses. Habitat conversions for urban development outside of the park may eliminate those important habitats, and cause population declines or local extinctions for species inside the park that depend upon those habitats for persistence. Unique habitats that may be essential to ecosystem functioning within parks include ephemeral habitats which provide specific life history requirements at certain times of the year (Figure 15c), corridors that provide access to other habitat patches (Figure 15d), and very productive habitats which, through immigration, supplement park populations (i.e. source habitats; Figure 15c).

Ephemeral Habitats

Some organisms use specific habitats for a limited period of time in order to obtain resources critical for the fulfillment of a certain life history stage. Species may use these ephemeral habitats seasonally, or possibly only once in their lifetime. Examples of ephemeral habitats include wintering areas used by taxa that migrate locally from summer habitats with harsher climates, breeding grounds for taxa with specific breeding habitat requirements that differ from their normal home range habitat, or areas of refuge for juveniles from environmental and biological stresses. Given that these ephemeral habitats include essential breeding, nursery, and wintering areas, their elimination outside of parks could result in the inability of certain species to persist within parks. Organisms depend on these important habitats because they are usually more productive than surrounding areas. However, humans often prefer to settle in these productive areas as well (Hansen and Rotella 2002), so that surrounding urban development may be a significant threat to the persistence of unique habitats outside parks. Some common impacts of urban development are the draining of wetland and riparian areas that provide breeding and nursery habitats, and development of lowland pasture and agricultural areas used as winter range.

Habitat conversion which eliminates crucial ephemeral habitats around Heartland parks could have significant consequences for species diversity and ecosystem functioning within parks. This seems to apply equally to all parks, in that each has species that depend on special habitats at some point in their life history. For example, amphibians congregate in riparian areas and wetlands for breeding, resident birds migrate locally between different breeding and wintering habitats, fish migrate to specific spawning grounds, elk and bears move seasonally between lowland and upland habitats, and juvenile fish concentrate in shallow side channels of slower-moving water. These important habitats may exist in-part or wholly outside of park boundaries, and so their conversion to urban environments may influence rates of reproduction, recruitment, and mortality, and lead to significant population declines for certain park species.

Ecosystem functioning and species diversity within smaller Heartland parks (PERI, HEHO, LIBO, and HOSP) may be more heavily linked to the existence of seasonal habitats outside of park boundaries. Smaller land areas generally support fewer habitat types, so the chance that the boundaries of smaller parks will encompass all crucial habitats is much less than for larger parks. However, seasonal habitats are probably very important for OZAR, CUVA, and BUFF as well. Although these parks are larger in size, their boundaries were drawn mainly to encompass important river ecosystem components, and not for the inclusion of a variety of habitats; therefore, habitat heterogeneity may be somewhat limited in these parks as well. Also, because there is more natural habitat surrounding the forest parks than agricultural parks, unique habitats may be more abundant outside, and the linkages with forest park ecosystem processes therefore relatively strong.

Dispersal and Migration Corridors

Migration routes and dispersal corridors are natural habitats that provide food and cover for organisms when traveling between the park and remnant habitats. Habitat conversion surrounding parks may disrupt these movements by either converting corridors to inhospitable environments through which organisms will not travel, or by intensifying the human-wildlife interface along remaining corridors and causing increased animal mortality along travel routes. Restricting migration would deprive organisms of seasonally important resources, such as those needed for wintering or breeding, and would have the same ecological consequences as eliminating those distant habitats all together. Furthermore, inhibiting dispersal to other populations would reduce gene flow between populations, and increase the possibility of genetic drift and inbreeding, threatening long term population viability and persistence. Studies have shown the importance of corridors for the movement of migrating or dispersing mammals (Wegner and Merriam 1979, Bolger et al. 1997, Mader 1984), birds (Haas 1995, Machtans et al. 1996), reptiles (Templeton 2001), and insects (Mader 1984), and the existence of these protected travel routes is crucial for maintaining landscape level connectivity. Therefore, the elimination of travel corridors and the loss of connectivity between park ecosystems and remnant habitats could reduce populations and increase the risk of local extinction for certain park species.

Many of the Heartland parks are in close proximity to remnant tracts of natural habitat with which they may be ecologically connected by corridors (Figure 1). These corridors may include both terrestrial and aquatic travel routes that allow for access to important habitats that are not adjacent to park lands. The elimination of travel corridors for migration and dispersal would negatively influence almost all taxa, except those especially tolerant of human landscapes and activities. However, the conversion to urban environments would especially impact populations with limited dispersal abilities, such as some insects and herpetofauna. Also, the risk of isolation would be especially high for forest-obligate organisms, because relatively open urban landscapes do not resemble forest corridors; they do not provide the resources required for foraging, or the forest structure needed as cover from predators. Additionally, converting natural areas to urban landscapes would intensify the human-wildlife interface along corridors, leading to increased mortality rates for those taxa especially susceptible to road mortality (e.g. small and medium mammals and herpetofauna) and at high risk for poaching (e.g. raptors and medium sized mammals).

Corridors are especially important in fragmented landscapes, so may play a very important role in maintaining ecological functioning within Heartland parks. Most of these potential corridors within the Heartland region are privately owned parcels of land, so are at a greater risk of conversion to urban landscapes than the public lands that they link. Agricultural parks may have stronger ecological linkages with corridors because the surrounding landscapes are generally more fragmented than forest parks, and organisms may rely more heavily on corridors as travel routes to distant habitat patches. Additionally, comparable amounts of habitat conversion around agricultural and forest parks may have more severe ecological consequences for agricultural parks whose smaller corridor areas would get consumed by development more quickly. However, corridors are likely very important for forest parks as well because all three of these parks are in close proximity to very extensive tracts of National Forest land (OZAR and Mark Twain National Forest, BUFF and Ozark National Forest, and HOSP and Ouachita National Forest) which probably significantly contribute to ecological functioning and the persistence of species within parks.

Population Sources

When reproduction within a certain population exceeds adult mortality and dispersal, that population is termed a “source” in that it exports excess individuals to other regional populations. Certain habitats may be termed source habitats if they generally produce more individuals than needed to sustain the population within that habitat. Other habitats may be termed “sink” habitats if reproduction generally does not compensate for adult mortality; these populations would generally become locally extinct without immigration (Pulliam 1988). Immigration from source habitats reduces the risk of local extinction by supplementing population numbers and introducing genetic diversity (Brown and Kodric-Brown 1977), allowing populations to persist in inferior sink habitats.

Researchers have established the existence of source-sink dynamics for many taxa throughout North America, including birds (Donovan et al. 1995, Robinson et al. 1995, Hansen and Rotella 2002, Vierling 2000), mammals (Kreuzer and Huntley 2003, Gaona et al. 1998, Paradis 1995), insects (Rosenheim 2001, Thomas et al. 1996, Fronz and Kindlemann 2001), and amphibians (Gill 1978, Semlitsch and Bodie 1998), and have stressed the importance of maintaining connectivity between populations. This source-sink phenomenon reinforces the existence of ecological linkages across the landscape, and emphasizes the importance of considering the consequences of large-scale changes on local ecosystem functioning for Heartland parks.

Certain park species may depend on immigration for persistence, so the conversion of surrounding habitats that support source populations could significantly impact species diversity, community composition, and ecosystem functioning within parks. Species especially impacted would be those for which habitat inside the park is limited, but more abundant outside of the park, such as riparian-obligate species, or interior forest species that maintain larger populations in large forest tracts (e.g. National Forest lands). Also, species that have relatively high dispersal abilities may depend more heavily on immigration for local persistence than species with limited individual home ranges; this may be especially important for species with small park populations (e.g. threatened, endangered, or rare birds, bats, or butterflies). The loss of source populations outside of parks could lead to the local extinctions of these populations in sink habitats inside parks.

Considerations for source-sink dynamics are probably important for all parks, as they are all surrounded by tracts of natural habitat that could be contributing immigrants to park populations. Ecological linkages with source habitats may be especially strong for the smaller agricultural parks, which may support smaller populations than forest parks, and depend more heavily on immigration to sustain park populations. Conversely, forest parks are surrounded by relatively contiguous forest which is more likely to support source populations than fragments (Donovan et al. 1995). Forest park populations may not depend on immigration for persistence, but may themselves be sources. Habitat conversion may turn populations within parks and surrounding areas into sinks due to edge effects and habitat loss, disrupting metapopulation dynamics within the region and causing species declines (Rogers et al. 1997).

WATER POLLUTION AND DISRUPTION OF HYDROLOGIC FLOW REGIMES

As areas surrounding parks undergo urban development, stressors on aquatic systems will likely intensify (Pringle 2000, Whipple et al. 1978). Most of the Heartland parks are to some degree concerned about land use changes which negatively influence park water quality and quantity. HOSP, OZAR, BUFF, and CUVA are especially concerned about preserving the physical and biological characteristics of water flowing through their parks because large rivers and extensive spring systems are major components of park ecological processes, and water quality greatly influences cultural and recreational opportunities.

Residential, commercial, and industrial development can change the characteristics of water in many ways (Roy et al. 2003, Nelson and Booth 2002, Paul and Meyer 2001, Lenat and Crawford 1994). Septic systems and sewage treatment plants associated with residential areas can overflow and pollute surface and ground water with nutrients and bacteria; water discharges from industrial plants can introduce heavy metals and chemicals into aquatic systems; the establishment of roads and clearing of land within residential and commercial areas can cause erosion and increase the amount of silt flowing into streams and rivers; stormwater runoff from lawns and impermeable surfaces can introduce nutrients and chemicals into surface waters, as well as disrupt the timing and amount of hydrologic flows; and groundwater withdrawals and dam construction for the creation of reservoirs and flood control can alter instream flows and hydrologic regimes, causing episodes of dewatering or flooding. All of these alterations change the characteristics of material and energy flowing through parks which are downstream from urban development, and disrupt ecological functioning within aquatic systems in parks.

Alter Characteristics of Material Flowing through Reserve

Ecological processes are often strongly linked to the characteristics of materials moving across the landscape. The physical and biological composition of water flowing through the watershed is one example of an ecological flow that is especially important to aquatic ecosystems. Aquatic organisms depend on the flow of water to create and maintain habitat, food resources, and essential nutrients and minerals.

Water pollution originating from land use activities outside of the park can alter the composition of water that flows through the park and impact various aspects of aquatic systems (Figure 15e). Increased silt deposition can decrease the availability of gravel spawning habitat for fish and attachment sites for invertebrates (Osmundson et al. 2002, Chutter 1969, Brusven and Prather 1974, Berkman and Rabeni 1987), and smother eggs and larvae (Soulsby et al. 2001), as well as fill in shallow pools and side channels which are important habitat for amphibians and juvenile fish (Gozlan et al. 1998, Giannico and Hinch 2003). Furthermore, siltation increases the amount of total suspended solids (TSS) in the water, which increases turbidity (i.e. decreases the clarity of the water) and decreases the photosynthetic potential of submerged aquatic plants (Blanch et al. 1998, Parkhill and Gulliver 2002), leading to reduced plant vigor and the depletion of dissolved oxygen in water. Inputs of nitrogen and phosphorus from urban runoff can fuel rapid growth of otherwise limited algae populations (Paul and Meyer 2001), creating massive blooms and increasing TSS, having similar impacts as already mentioned for increased silt deposition. Inputs of heavy metals and toxic chemicals from industrial discharges can have both direct and indirect ecological effects on aquatic organisms. Accumulations in the water can cause direct mortality and restrict the amount of quality (i.e. non-polluted) habitat for populations to occupy (Matthiessen and Law 2002, Austin 1999, Akoosh et al. 1998, Landahl et al. 1997). Also, lower concentrations of metals and toxic chemicals in the tissues of animals can cause significant accumulations in organisms along the food chain, and result in indirect population declines from poisoning and reduced fecundity in top level predators (Cabana and Rasmussen 1994).

Hydrologic regimes are also important landscape level ecological flows which influence the transport of energy, nutrients, sediments, and organisms throughout the watershed (Figure 15f). The characteristics of these flows within a river system will define volume and depth of water, timing of water delivery, water velocity, and sediment movement, all of which significantly influence habitat and life history processes for aquatic and riparian organisms. Urban development can lead to population declines for aquatic organisms by changing flow characteristics (Whipple et al. 1978, Paul and Meyer 2001, Booker 2003) and disrupting the connectivity of ecological processes. For example, dams can create a physical barrier to migration and dispersal for fish and invertebrates, genetically isolating park populations and prohibiting access to upstream spawning sites (Benstead et al. 1999, Cada 1998, Gehrke et al. 2002). Furthermore, dams often store excess water in reservoirs, decreasing the amount of water deposited downstream, drying up shallow pools and side channels used by juvenile fish and amphibians. Reservoir storage also eliminates regular seasonal pulses of flooding which contribute to dispersal, establishment, and regeneration within riparian plant communities (Scott et al. 1997). Additionally, runoff from impermeable surfaces often intensifies peak flows (Jennings and Jarnagin 2002, Finkenbine et al. 2000), creating unnatural flooding and scouring conditions which may displace fish eggs, juveniles, and invertebrate larvae downstream, while also uprooting and inhibiting the regeneration of aquatic and riparian plants. Channel scouring also sweeps large woody debris (LWD) downstream and erodes streambanks (Finkenbine et al. 2000, Wang et al. 2001), decreasing the amount of quality fish habitat in areas most impacted by urban development.

The magnitude of the influence of water pollution and the disruption of hydrologic regimes will depend upon the location of a park within the watershed, with areas located lower in the watershed at greater risk of suffering from the cumulative impacts of upstream alterations. In the HTLN, most parks are located in the upper or middle part of the watershed, so may be at risk from cumulative impacts of development upstream or within tributaries. Additionally, development surrounding parks will influence characteristics of water in close proximity no matter the location within the watershed, so alteration of water resources from nearby human activities may also be a significant risk to ecological integrity within parks. Currently, characteristics of water flowing through most watersheds within the region are moderately altered by water pollution (Figure 6) and hydrologic modification (Figure 7). Growth in urban development in the past fifty years has likely contributed to higher levels of pollution (Whipple et al. 1978) and an increase in dam construction (Figure 10), so consideration for the possible effects of future growth are warranted. The ecological consequences of water pollution and disrupted hydrologic regimes are more significant for river parks than land parks because the dominant reserve ecosystem processes and top management priorities depend heavily upon the maintenance of river function. However, most land parks have creeks or rivers that support riparian and aquatic ecosystems which are important for the preservation of overall park integrity.

INCREASED HUMAN POPULATION DENSITY

Residential, industrial, and commercial development introduces significant levels of human activity permanently to the landscape. Therefore, the mere presence of human settlements and high population densities around parks can considerably influence ecosystem functioning (Figure 15g). This applies to all Heartland parks, even those located within landscapes dominated by agriculture, because the intensity of human activity is much greater in urban than in rural landscapes. For example, increased levels of recreation around and within parks associated with high population densities may elevate levels of direct and indirect negative human impacts on park natural resources. Additionally, the presence of human settlements in close proximity to parks can introduce edge effects which relate to both the intensified human-wildlife interface and the introduction of human-adapted species to the landscape.

Increase Recreational Use

People residing close to a park may look for the majority of their recreational opportunities there, especially if the park is a natural refuge in an otherwise human-dominated landscape. Urban development creates population centers in close proximity to parks, making it more convenient for people to recreate in and around them. Additionally, the development of private land around park borders can create more access points into the park, and encourage recreational use in formerly remote areas.

Increased levels of recreation can negatively influence park ecosystems in many ways. For example, plant communities can suffer when hikers wander off trails and trample and erode otherwise pristine areas, or when people pick the flowers of rare species. Additionally, the seeds of exotic plant species are often unintentionally dispersed by humans into remote park areas. Also, increased numbers of people inside the park can result in higher incidences of human-wildlife interactions. This can be especially detrimental to "dangerous" animals, such as bears and snakes, that may have to be relocated or euthanized as a consequence, or to juveniles which are relatively immobile, such as bears, birds, and deer, which would be unable to flee and be most susceptible to direct contact with humans. Lastly, increased motorized recreation on rivers and lakes within or upstream of parks can increase water pollution, increase the incidences of harassment, displacement, and direct mortality of aquatic organisms, and lead to the unintentional and intentional introductions of exotic fish (e.g. rainbow trout), aquatic invertebrates (e.g. zebra mussel, Asian clam), and plants (e.g. purple loostrife) which out-compete and prey on native species.

Within the HTLN, parks are often the largest tracts of public lands in an otherwise privately owned landscape, so outdoor recreational opportunities for people living in the area may be concentrated within parks. If rates of human settlement continue to grow as they have in the past fifty years (Fig. 9), more people will likely visit parks on a regular basis, and park resources may suffer consequences related to overuse. This is probably a significant concern for all parks, as growth rates are skyrocketing throughout the entire region (Table 7). However, increases in recreational use within forest parks may be less drastic. Forest parks are surrounded by a larger proportion of National Forest lands than are agricultural parks, so recreational activities may be more spread out across those additional public lands, and less concentrated within park boundaries.

Introduce Edge Effects

Increased human population and the establishment of permanent settlements around parks can introduce edge effects associated with the newly created or intensified interface between park ecosystems and human activities. The influences of human presence and activity within the landscape can alter ecosystems on a large scale, with impacts often creeping into bordering natural areas. The introduction of exotic and human-adapted opportunistic species is closely correlated with human population density (McKinney 2001), and is probably one of the greatest negative impacts that humans can have on nearby park ecosystems. Animals associated with urban landscapes include cats, dogs, deer, raccoons (*Procyon lotor*), striped (*Mephitis mephitis*) and spotted (*Spilogale putorius*) skunks, and corvids (family Corvidae), all of which can cause increased mortality rates and lower recruitment for birds (Andren et al. 1985, Wilcove 1985, De Santo and Willson 2001), small mammals (Matthiae and Stearns 1981, Bock et al. 2002, Liberg 1984), and plants (Alverson et al. 1988). Exotic plant species which escape from landscaped residential areas can become established in natural areas and out-compete native plants, resulting in decreased species diversity within plant communities. The presence of high levels of human activity can also influence park populations directly, by contributing significant amounts of pollution into downstream aquatic systems (Whipple et al. 1978), and causing direct mortality through increased incidences of poaching and road-kill (Woodroffe and Ginsberg 1998). These edge effects can have detrimental consequences, including decreased habitat quality, increased mortality rates, and reduced rates of recruitment, for populations residing along the periphery of the park.

Taxa that may be especially influenced by edge effects are birds or small mammals that are susceptible to introduced predators, any species that is highly impacted by poaching [e.g. raptors, deer, coyote (*Canis latrans*), rabbits (*Sylvilagus* spp.)] or road mortality (e.g. small- and medium-sized mammals, amphibians), native plant species that are competitively excluded by exotic plants, and species which humans do not tolerate (e.g. snakes, bears) that will be displaced. Additionally, the spread of exotic species introduced by upstream human activities can impact native fish and aquatic invertebrates within park waterways, as well as riparian and aquatic plants.

The ecological consequences may be great for Heartland parks in general, as edge effects can create new problems for park ecosystem functioning, as well as exacerbate historical problems stemming from long-established agricultural settlements. Although agricultural parks have experienced a human presence in the landscape for a long period of time, that exposure has been within a relatively rural environment, with population and housing densities much lower than are typical of urban areas. However, the characteristics of the landscape are changing; since 1950, farmland acreage has declined drastically (Fig. 11) and housing and population densities around agricultural parks have skyrocketed (Figure 8), so edge effects related to increased human activity and presence are also most likely intensifying. Edge effects may be even more detrimental for forest parks than agricultural parks. Forest parks have historically experienced lower population and housing densities, so the consequences of edge effects may be more drastic than for species within agricultural parks that have already adapted to higher levels of human activity.

Implications for Individual Parks

Although there are general patterns in land use change across the Heartland region, there is also a lot of variation between parks. Park landscapes range from relatively pristine areas experiencing little growth (OZAR), to rural areas that are growing rapidly (BUFF, HOSP, and PERI), to urban areas experiencing smaller population increases (CUVA) (Figure 9). Because of this, and because different parks have different management priorities, it is important to consider the most significant implications of land use change for individual parks.

Cuyahoga Valley National Park

There are more than 2.5 million people residing in the counties around CUVA (Figure 3), so the landscape is largely urban and suburban (Figures 1a and 2). Consequently, managers of CUVA are concerned with preserving the natural resources of the park within this urban environment. Although population growth in the region around CUVA is actually relatively low compared to other Heartland parks (22% since 1950; Table 7), patterns of human settlement at the county level indicate that people are moving into the rural areas of the region. For example, the two least populated counties in 1950, Geauga and Medina, have experienced population increases greater than 200% over the past fifty years, while the metropolitan county of Cuyahoga has stayed relatively steady (Figure 8). This corresponds with the significant loss of farmland in all counties surrounding the park (Figure 11). Growth in rural areas could have significant consequences for park ecosystems, as areas around the park experience greater levels of water pollution, habitat loss, and general human activity, and contribute additional stresses on park systems already influenced by urban surroundings.

The urban nature of the park landscape creates unique challenges for park managers that most other park managers within the HTLN do not encounter. For example, the region around CUVA experiences severe water quality problems while most other parks have relatively good water quality (Figure 6). However, the park itself is a natural refuge in this otherwise human-dominated landscape, and park management priorities focus on maintaining ecological integrity. These include limiting the spread of exotic plants and maintaining native plant communities, and preserving aquatic and wetland ecosystems. The land use changes relevant to these concerns are those which introduce edge effects into the park, alter the characteristics of ecological flows across the landscape, and increase recreational use and human disturbance.

Ozark National Scenic Riverways

OZAR is the most rural and isolated of all Heartland parks. Average current population and housing densities (23 and 11 per square mile, respectively; Figures 3 and 4) and number of houses gained per square mile in the past fifty years (+9 houses; Table 7, Figure 9) are the lowest of the entire region. Consequently, OZAR enjoys good water quality (Figures 6 and 13), low levels of hydrologic modification (Figures 7 and 13), and relatively intact surrounding forest habitats (Figure 1b, Table 5). However, relative increases in housing density in the region since 1950 are extremely high (almost 450%; Table 7, Figure 9), indicating that urban expansion within the region is an important future land use change concern.

In many ways, the natural landscape surrounding OZAR maintains the same characteristics as ecosystems within the park, so ecological functioning is likely operating on that broader landscape level. Therefore, monitoring land use changes which alter the natural characteristics of the landscape may be crucial for maintaining and preserving ecological functioning within the park at the level it is at today. Because maintaining the pristine characteristics of surface water and springs is a primary focus of park management efforts, it may be especially important to consider the consequences of land use changes which alter ecological flows and compromise aquatic integrity. Although OZAR currently enjoys relatively “healthy” watersheds, urbanization can contribute significant amounts of water pollution and lead to severe hydrologic modification (Whipple et al. 1978), so trends showing increases in urban development warrant legitimate concern. Additionally, because OZAR is surrounded by relatively contiguous forest, ecological functioning within the park may depend heavily on the maintenance of surrounding habitats, and conversion to urban landscapes may be a significant threat to the integrity of terrestrial ecosystems. It would be relevant to also monitor land use changes which may reduce functional ecosystem size or eliminate unique habitats outside of the park.

Pea Ridge National Military Park

The landscape surrounding PERI has historically been dominated largely by agricultural activities (Figure 1a), and has been characterized by low to moderate population densities (Figure 9). This historically moderate level of human settlement is reflected in characteristics of the landscape; water quality (Figure 6) and hydrologic flow regimes (Figure 7) have been moderately altered by human activities. However, due to the parks close proximity to the booming city of Fayetteville, the region around PERI has been exploding in population (Figures 8 and 9), and has experienced the greatest relative growth of all Heartland parks (159% increase in population; Table 7). Furthermore, population for the county within which PERI is located has increased more than 300% (a much greater increase than all other surrounding counties; Figure 8), so much of the urban expansion is occurring within very close proximity to the park. Therefore, monitoring of land use change around PERI, and concerns about the possible ecological consequences of that change are very relevant.

PERI is a relatively small park (Table 2), so may depend on external habitats to sustain species with large park populations or home ranges, or may depend on surrounding landscape features for the maintenance of large-scale ecological processes. Habitat conversion is an important consideration for park managers interested in maintaining biodiversity, as habitat loss may further isolate the park from surrounding forest tracts (especially large tracts to the northwest and east), potentially reducing functional ecosystem size or eliminating unique habitats. This may be especially relevant to maintaining the integrity of rare and threatened herpetofauna populations, a top priority of park managers, which depend on wetlands or riparian areas outside of the park. Furthermore, increased population density close to the park may lead to increased levels of recreational activity within the park and introduce edge effects which exacerbate current problems with exotics, or lead to an intensified human-wildlife interface. PERI does not have a significant aquatic component, so concerns about land use changes which alter ecological flows may not be as relevant as changes related to habitat loss.

Hot Springs National Park

The broader landscape surrounding HOSP has historically been rural, characterized by low population densities (30 people per square mile in 1950) and few industrial influences. However, the city of Hot Springs within and surrounding the park has experienced a population explosion in the past fifty years (Figure 8), with a 745% increase in housing density and 90% overall population growth (Table 7). The decline in the rural nature of the landscape is further demonstrated by the 50% decrease in farmland acreage (Table 7, Figure 12), one of the greatest losses of farmland of all Heartland parks. Urban expansion is therefore an important consideration for park managers.

Park mandates focus on the maintenance of pristine water quality within the park, and this is a top park priority. The integrity of the HOSP watershed is still relatively high, with no severe water quality problems; however, some surrounding watersheds have more severe water pollution problems (Figure 6). Considering that the recharge basin for the underground springs within the park is ill-defined (NPS 2002), general landscape level monitoring may be the only way to understand potential threats to park water quality. Furthermore, urbanization contributes greater amounts of pollution than other land use activity (Whipple et al. 1978), so monitoring of land use changes within the region may be crucial for predicting or mitigating future water quality problems caused by urban expansion. Land use changes altering the flow of water through the park are the biggest threat to water quality, and focusing monitoring efforts on these changes are probably most relevant to park management priorities. Additionally, increased population within the area surrounding the park may lead to increases in recreational use within the park, another threat to park water resources.

Although the main park management priorities focus mostly on water quality issues, the park terrestrial landscape is characterized by large tracts of contiguous forest (Figure 1b), and has the highest proportion of natural land cover of all Heartland parks (86% of the landscape;Table 5, Figure 2). This forest likely plays an integral role in maintaining terrestrial ecosystem functioning within the park. Monitoring of land use changes that convert habitat to urban landscapes, creating edge effects, reducing functional ecosystem size, and eliminating important habitats, may be beneficial for predicting and mitigating future effects on terrestrial ecosystem functioning.

Lincoln Boyhood National Memorial

LIBO is located within a largely agricultural landscape (Figure 2), and has been for centuries, so ecosystems within the park most likely adapted long ago to rural human settlements and moderate levels of human activity. However, in recent decades the region around the park has been transitioning from rural to more urban, with housing densities increasing 339% since 1950 (Table 7, Figure 9), and landscape characteristics reflect this change. The park landscape experiences water quality that is moderately altered by human-caused pollution (Figure 6), has high levels of hydrologic modification (Figure 7), and a significant industrial presence (the highest of all Heartland parks, with one industrial site every 17 square miles; Figure 5). Consequently, park managers are concerned about how this transformation from a rural agricultural landscape to one that is more urban will impact park natural resources.

LIBO is a largely terrestrial park, so park management priorities focus on preserving and restoring forest health and associated wildlife populations. Because the park is located within a fragmented landscape, land use changes that disrupt habitat connectivity and further isolate the park from external remnant forest tracts (especially those to the northwest and east), may be an important focus for establishing land use change monitoring priorities. Urban development which eliminates unique habitats such as corridors, source habitats, and seasonal habitats may significantly influence park ecological functioning, and may hinder efforts to restore wildlife populations within the park. Additionally, increases in human population and residential settlements around the park may intensify edge effects and exacerbate the spread of exotic plants within the park, as well as increase recreational use and human disturbance inside of the park.

Herbert Hoover National Historic Site

HEHO is different from the six other Heartland parks in that it is dominated by prairie ecosystem processes. The surrounding landscape has historically been, and still is now, largely planted cropland (Figures 1a and 2). However, like most parks surrounded by agriculture, the rural landscape is becoming more urban, with an increase of greater than 200% in housing and 67% in population density in recent history (Table 7). Although the overall decline in farmland acreage was the smallest for HEHO (-14%; Table 7, Figure 12) compared to other Heartland parks, certain counties in the region surrounding the park are experiencing substantial declines. For example, Linn and Johnson counties to the west of the park have lost over 20% of their farmland acreage (Figure 11). These counties also have the largest population centers in the area and are experiencing the greatest growth (Figure 8), indicating that urban expansion into rural areas near the park is a significant concern for park managers. The region surrounding the park already experiences some water quality problems (Figure 6), so greater levels of human activity and settlements in the region may further exacerbate these problems.

Water quality and quantity within Hoover Creek are an important focus for park managers. Urban expansion outside of the park could exacerbate these problems by increasing pollution, sedimentation, and runoff, and inhibiting park efforts to restore creek functioning. Monitoring should therefore focus on land use changes which alter the characteristics of the water flowing through the park, including those changes that disrupt hydrologic regime and negatively impact water quality. Additionally, restored prairie habitats within the park provide a unique refuge where prairie species and ecosystem processes can persist in an otherwise agricultural landscape. Any land use changes which isolate these small prairie remnants from corridors, source habitats, and other unique habitats outside of the park could be very detrimental to the persistence of park prairie species. Lastly, urban expansion may contribute to the spread of exotic species across the landscape and hinder prairie restoration and maintenance efforts.

Buffalo National River

BUFF is surrounded by large tracts of contiguous forest and scattered pastures (Figure 1b). The area is characterized by low housing densities (16 houses/mi^2, second lowest of all Heartland parks; Figure 4), but has experienced large relative population increases over the past fifty years (90% growth; Table 7, Figure 8). However, absolute growth is still moderate (gained only 14 houses per square mile; Table 7, Figure 9), so the region maintains characteristics of a rural landscape. Water quality is good throughout the watershed (Figure 6) and hydrologic modification of the Buffalo River watershed is low (Figure 7), indicating good overall watershed health. However, surrounding watersheds experience impaired water quality and higher levels of hydrologic modification, which may alter surface and groundwater instream flows into the Buffalo River, and threaten watershed integrity within the larger region surrounding the park. Expanding urban development in the region, as well as threats from surrounding watersheds, could alter ecological functioning within the park in the future.

Understandably, maintaining aquatic integrity is one of the primary concerns of park managers. Monitoring land use changes which alter the flow of water through the park (including disrupted hydrologic flows and water pollution) may be the best strategy for maintaining the integrity of the surface waters of the Buffalo River in the future. These land use changes could also negatively impact water quality of underground springs, which provide instream flow to the river and habitat to various native organisms. Additionally, aquatic integrity may be threatened by the spread of exotic plants and aquatic organisms throughout park surface waters, so it may be important to monitor land use changes associated with increased levels of human activity, which contributes to edge effects.

In addition to its substantial aquatic ecosystems, BUFF is surrounded by extensive tracts of forest which likely contribute to ecological functioning within terrestrial ecosystems inside the park (Figure 1b). Loss of unique habitats or corridors which provide connectivity with National Forest land, as well as overall habitat loss and reduced functional ecosystem size, could negatively impact park terrestrial populations, especially larger organisms such as bears and elk, and rare species such as bats and herpetofauna.

Potential Indicators

One of the primary goals of this study was to identify indicators that can be used by park managers to monitor surrounding land use changes in the future. Appropriate indicators are landscape-level demographic and ecological attributes which are sensitive to change, and are associated with the mechanisms which link land use changes to ecological functioning within parks. (See Table 8 for data formats and sources.)

Land Cover Change

Land cover and land use change may be one of the most important components of a long-term monitoring plan. Quantifying the occurrence of land cover/use classes within a particular area over multiple time periods allows for the detection of change in the relative occurrence of natural, agricultural, and urban cover types, and provides an index for the potential direct (e.g. decreased functional ecosystem size through loss of habitat area, elimination of unique habitats) and indirect (e.g. edge effects, altered ecological flows across landscape, increased human disturbance) ecological impacts of urbanization on park resources. Land cover/use characterization may be an important tool in the monitoring programs of all Heartland parks, because it captures changes related to urbanization which are equally relevant to all park landscapes and ecosystems.

The National Land Cover Dataset (NLCD), created and maintained by the USGS EROS Data Center (EDC), is a program in which classified land cover/use maps of the conterminous U.S. are derived from satellite imagery, and updated every five to ten years (Vogelmann et al. 2001). Completed maps are distributed at no cost on the USGS EDC website, and the only manipulation required includes the aggregation of classes, and possibly reprojection of the spatial data. With a spatial resolution of 30 meters, land cover change analysis at the scale previously presented in this report (i.e. county-defined and watershed-defined park study areas) is appropriate (especially with the original 21 classes aggregated up to three broad land cover classes), and has been used at this scale by other researchers within the U.S. (Vogelmann et al. 2001). Therefore, the NLCD is time and cost efficient, as well as a consistent and accurate data source for examining trends in regional land cover/use changes occurring around parks over five to ten year time periods.

If monitoring land cover change on a shorter time interval than five or ten years is necessary, managers can instead create their own land cover maps as an alternative to using NLCD maps. This includes obtaining Landsat satellite imagery, and classifying these images using spectral characteristics, aerial photo interpretation, and ground-truthing (Vogelmann et al. 2001, Wright Parmenter et al. 2003). The creation of maps specific to Heartland parks would allow for analysis of land cover change every one to two years instead of the five to ten years provided by the NLCD. Additionally, land cover maps specific to local regions would have higher accuracy potential than national maps because of the ability to conduct more intensive ground-truthing efforts in the smaller area. However, creating regional maps from satellite imagery is very labor intensive, requiring the expertise of a Geographical Information System (GIS) and Remote Sensing Specialist, as well as extensive ground-truthing. Also, this methodology requires the purchase of satellite and aerial photo images, requiring substantially more financial resources than if using the virtually no-cost NLCD maps.

Population Density

Population density is a demographic measure which can be especially useful for monitoring patterns of urbanization, because the influx of people into formerly rural areas indicates a transition to a landscape dominated by urban activities and land cover types. Increases in population density around parks indicate that negative ecological impacts of urbanization may potentially influence park resources, with greater rates of increase indicating greater potential impacts. These land use changes may be linked to park ecosystem functioning through mechanisms which are related to higher levels of human activity within the landscape, including edge effects stemming from the intensification of the human-wildland interface, alteration of hydrologic flows, and human recreation and disturbance. Population density is an index of urbanization that is applicable to all landscapes, and is measured consistently across space and time, so can be an equally relevant monitoring tool for all Heartland parks.

Since 1990, the USCB has been collecting and reporting population statistics at sub-county levels (i.e. sub-divisions called “block groups”), and will continue to do this in a consistent manner for all future decennial censuses. Therefore, monitoring future changes in population characteristics surrounding parks can be done with more focus on local areas (Figure 16), compared with the county-level analysis reported previously in this paper which represented historical patterns of changing population density around parks (Figure 8). This greater resolution will allow for more detailed analysis of change within the park landscape; for example, population growth trends can be examined at varying distances from park boundaries or other important landscape features. Population statistics at the block group level are now reported on the USCB website, and can be downloaded in a spreadsheet format ready for analysis. Also, base maps delineating census block groups are available for all states on the USCB website, so the population data can be geographically referenced for spatial analysis. However, this block group data is available only for each decennial census; annual population estimates are available from the USCB only at the county level. Therefore the monitoring method used for quantifying changes in population density will depend on the temporal scale of concern as well as the level of spatial resolution needed for detecting relevant patterns.

Housing Density

Housing density is another indicator which represents demographic trends, and rates of increase in housing density often closely reflect increases in population density. However, housing density is a more direct measure of the extent of urban settlements within a region, and may better represent the potential impacts of ecological linkages between habitat conversion and park ecological functioning (i.e. edge effects related to loss of interior forest, decreased functional ecosystem size due to habitat loss, and the elimination of unique habitats), in addition to indirectly measuring disturbances created by human activity (i.e. edge effects stemming from the intensification of the human-wildland interface, alteration of hydrologic flows, and human recreation). Furthermore, although population and housing densities have both exhibited large increases in recent decades, housing density has increased at a much greater rate around Heartland parks than population density (Table 6). This trend is evident across the U.S. as well as globally, and can be explained by a decrease in the number of occupants within the average household, which creates a need for more houses per capita (Liu et al. 2003). Therefore, monitoring both population and housing density may give insight into different patterns and rates of growth, as well as help to understand the potential ecological impacts related to the different types of growth.

Methods for monitoring housing density are the same as for monitoring population density. The USCB reports population and housing characteristics at the block group level as a part of all decennial census reports, so these indicators can be monitored simultaneously in the future. However, housing density estimates are not provided at the county level by the USCB annually as are estimates of population density. If managers want to monitor changes in housing density within a shorter time period than ten years, information about each house within a certain county, including the year the home was built and its general location, can be obtained from the County Tax Assessors office in the form of property tax records (Hernandez et al. in prep). New homes are usually assessed for property tax value soon after they are completed, so the information should be current and available for monitoring every one to two years. Monitoring housing density for this shorter time interval (as opposed to the ten year data provided by the USCB) may give managers a greater ability to anticipate any potential negative ecological consequences of urban development. Additionally, housing information originating from property tax records is provided at the section level (one square mile), so the finer scale of this data may allow for more detailed analysis of local trends. However, obtaining housing density information in this manner is much more time consuming, as visits to local county and state offices are often necessary (Hernandez et al. in prep), and individual records may have to be sorted through and compiled manually.

Landscape-level Wildlife Monitoring: Breeding Bird Survey

Wildlife populations are very good indicators of land use change, as many species are very sensitive to the changes in habitat and food resources that often accompany a shift in land use activities. Bird communities in particular have often been tested as indicators of biological integrity at a landscape scale (Rich 2002, O'Connell et al. 2000, Canterbury et al. 2000), because within any given area species richness and niche variety is often high compared with other taxa. Additionally, birds are generally very prolific, so researchers are able to collect a comparatively large amount of data on many species per unit of survey effort. Birds are especially good indicators of landscape changes related to urbanization, because certain species are strongly associated with different land use activities and land cover types. Multiple surveys conducted over time provide the information needed to detect changes in community composition related to these land use changes. Because birds of the Heartland region are largely terrestrial, population trends may best reflect landscape changes related to decreased functional ecosystem size, edge effects, and the loss of unique habitats. Birds are present across the landscape in all habitat types, so may be very useful indicators of landscape change for all Heartland parks.

The North American Breeding Bird Survey (BBS) is a program organized cooperatively by the USGS Patuxent Wildlife Research Center and Canadian Wildlife Service National Wildlife Research Centre. Survey routes spread throughout North America are visited annually, with participants recording the occurrence and abundance of all breeding birds detected at each station. Survey data is then compiled by BBS personnel and reported annually, and the public can access and download the raw data from the BBS website at no cost. In order to ensure a large enough sample size, analysis at the ecoregion level may be most appropriate for Heartland parks. Level III ecoregions based on Omernick (1987; digital maps provided on EPA website) have previously been used by BBS for analysis of trends, so may be the best basemap for Heartland park managers to use as well. Although the size of ecoregions are much greater than the size of the park study areas used so far in this report (e.g. BUFF, PERI, and OZAR all fall into the same ecoregion; Figure 17), trends in the occurrence and abundance of bird populations observed at this larger extent can be applied to local park landscape changes. Additionally, trends observed from BBS data can be compared with the results from local surveys conducted within parks, and similarities and differences may provide insight into the relationships between land use change and bird communities. In addition to monitoring trends in occurrence and abundance of certain species of concern, it may be helpful to consider groups of species with similar life history traits or habitat requirements (Canterbury et al. 2000, O'Connell et al. 2000). Trends of population decline or increase within a certain group may indicate the alteration of a certain resource upon which they collectively depend, and provide insight into the landscape changes that are influencing population trends.

Overall, the BBS program provides a consistent, cost-efficient, logistically simple data source for monitoring bird populations within the Heartland region. However, if park managers want to examine bird population trends within a more local area around parks (e.g. the county and watershed defined park study areas used previously for analysis within this report), they may also establish their own regional survey routes using methodology consistent with BBS protocol, and maintain those routes as a part of their park survey programs. Conducting breeding bird surveys generally consumes few financial resources and requires a relatively small time commitment (although familiarity with regional birds is necessary), so local surveys may be a feasible option for inclusion into a park monitoring program, and may provide valuable information about local trends in bird populations.

Biological and Physical Aquatic Surveys

Landscape level surveys which quantify the characteristics of aquatic ecosystems can be valuable indicators of watershed health, and provide information about changes in community structure and composition that may threaten aquatic integrity within surrounding watersheds. Spatial patterns of occurrence and abundance of fish and aquatic invertebrates within waterways that are connected with park waters can provide insight into possible source areas for both native and exotic species, patterns of invasion of exotics over time, and areas where native species of concern may be declining or increasing. Additionally, spatial and temporal patterns of water pollution and algae abundance can provide information about the sources of potential threats to park aquatic resources. Most importantly, discovering spatial and temporal trends in occurrence and abundance of certain species can aide in the determination of the location of possible stressors that may be threatening the integrity of aquatic communities, and disrupting ecological flows across the landscape. Landscape level trends can then be compared with those observed within park boundaries, and provide valuable insight into correlations between landscape change and park aquatic resources. Including aquatic indicators in a long-term monitoring plan may be most relevant for river-based parks (including CUVA, OZAR, and BUFF) and HOSP, for which aquatic resource monitoring is a top priority.

The USGS has established a National Water Quality Assessment (NAWQA) Program, which consists of aquatic sampling within 60 basins throughout the U.S. Five of the seven Heartland parks, including CUVA, BUFF, OZAR, HEHO, and PERI, fall within NAWQA study basins, so the NAWQA program may provide a consistent source of data for these parks that are interested in monitoring aquatic resources over time. NAWQA survey data includes information on fish, invertebrate, and algae species occurrence and abundance, as well as the habitat characteristics of each sampling point, and is available at no cost from USGS. However, the NAWQA study is conducted on only select waterways throughout the U.S., so results may be specific to those areas, and not applicable or relevant to park watershed. Additionally, results from NAWQA surveys are reported only every ten years, and park managers may be interested in examining trends within a shorter time interval. Local or state agencies may conduct similar surveys more extensively throughout the region, and this may be a better data source for the examination of local trends. For example, Arkansas Department of Environmental Quality conducts water quality, fish, and aquatic invertebrate surveys along many Arkansas waterways. Aquatic data collected by state (and federal) agencies is often reported to and distributed through the EPA STORET database, and can be downloaded from the EPA website in spreadsheet format. If local survey data is not readily available to parks, managers may instead consider establishing and maintaining their own survey stations along waterways that feed into park waters using methods similar to those used in the NAWQA program. Because conducting surveys and analyzing results can be very costly and require some specific expertise of aquatic communities, managers may want to consider cooperating with local universities or agencies to develop a joint monitoring program.

Hydrologic Flow Regimes

Hydrologic flow is another landscape level process that strongly influences aquatic resources within parks, and flow patterns can be important indicators of watershed integrity. Long-term monitoring of daily, seasonal, or annual flow regimes within regional watersheds can identify changes over time which represent the alteration of flows of water across the landscape and through the park. Monitoring hydrologic flow regimes can help park managers recognize and quantify changes in streamflow characteristics which may be due to urbanization, and anticipate the potential ecological consequences associated with those changes. Monitoring hydrologic flow regimes as indicators of land use change may be most relevant for river-based parks (CUVA, BUFF, and OZAR) and HOSP, which have significant concerns about maintaining aquatic integrity within park borders. HEHO also has concerns about flooding within the park, so may want to monitor flow regimes along waterways which may contribute to flooding problems.

The USGS has established an extensive hydrologic monitoring program which records and reports "real-time" flow characteristics at hydrologic gauges on waterways throughout the U.S. Streamflow (cubic feet per second) and stream stage (feet) are recorded and reported on the USGS real-time website approximately every four hours, and can be viewed and downloaded at no cost. Additionally, USGS provides a base map showing the locations of stations which can be downloaded and displayed in a GIS, so the hydrologic data can be geographically referenced for analysis and comparison of spatial patterns. Multiple gauge stations are located within most watersheds, so the USGS real-time data may provide a consistent, long-term, and cost- and time-efficient data source for monitoring hydrologic conditions within watersheds surrounding Heartland parks (Figure 18). State or county agencies may also sample regional waterways on a regular basis. If park managers would like to additionally monitor hydrologic conditions along streams not sampled by the USGS (for example, specific tributaries that feed into park waterways), they may be able to access that regional data, or work in cooperation with local agencies to establish and monitor new gauge stations using methods consistent with the USGS monitoring program.

Conclusions

Determining linkages between surrounding land use change and ecological functioning within parks is essential for understanding external disturbances and stressors which are impacting park resources. With understanding of important linkages, park managers can determine landscape-level indicators which will provide an index of relevant land use change over time, and represent the negative ecological impacts of these changes. Long-term monitoring of these indicators can help managers to determine patterns in land use change which may threaten future ecological integrity within parks. Furthermore, monitoring change of populations and within communities around parks will allow for recognition of patterns which may reflect current or future changes within park boundaries. Once park managers understand the potential causes of ecosystem degredation, they can work to restore park functioning through mitigation, or take actions to protect resources from future threats by helping to preserve important areas outside of parks (e.g. tributaries, wetlands, large remnant forest tracts) through cooperative agreements with other agencies and private landowners.

Acknowledgements

We would like to thank those within the Heartland Network for financial support and helpful suggestions, especially Brent Frakes, Janet Eckhoff, Phyllis Adams, and individual park managers. We also thank Kathy Tonnessen for her assistance in coordinating the partnership with NPS through the Rocky Mountain Cooperative Ecosystem Studies Unit.

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Table 1. Ecological mechanisms linking parks to land use change (modified from Hansen and Rotella 2002).

Mechanism	Type	Description	Examples
Effective or functional size of reserve	Species Area Effect	The number of species and population sizes within a reserve is influenced by its size. The functional size of reserves includes the reserve and the natural habitats surrounding the reserve. As natural habitats in surrounding lands are destroyed, the functional size of the reserve is decreased and risk of extinction in the reserve is increased.	Increasingly fragmented forests in Kenya have undergone extinctions of bird species as predicted based on change in their area.
	Trophic Structure	Characteristic spatial scales of organisms differ with trophic level such that organisms in higher trophic levels are lost as ecosystems shrink, allowing an expansion of lower trophic levels.	Loss of large predators on Barro Corranato Island and release of meso-predators.
Ecological Process Zones	Placement in watershed	Intense land use in upper watersheds may alter flows of water, nutrients, exotic species, and pollutants throught reserves lower in the watershed.	Despite being a vast wilderness, Grand Canyon National Park is heavily permeated with exotic organisms due to agriculture and water diversion higher in the watershed.
Unique Habitats	Ephemeral habitats	The region around reserves may also contain unique biophysical settings that are required by organisms within reserves to meet life-history requirements.	Ungulates in Serengeti National Park migrate to dry-season habitats outside of the park. Conversion of these habitats to wheat fields is associated with a 75% decrease in a Serengeti wildebeest herd.
	Dispersal or Migration habitats	Organisms require corridors to disperse among reserves or to migrate from reserves to ephemeral habitats.	Cougars in Florida Elephant in E Africa
	Population Source Sink Habitats	Unique habitats outside of reserves may allow high levels of population reproduction and survival and are "population" source areas required to maintain "sink" populations in reserves.	Rural home development in hot-spot habitats outside Yellowstone National Park favors exotic predators and has converted population source areas for native birds to sink areas. Consequently, extinction risk for these bird species has increased in the sink habitats in Yellowstone.
Edge effects	Edge effects	Negative influences from the reserve periphery (e.g., human caused mortality, invasive species) sometimes extend some distance into nature reserves.	Predatory mammals African nature reserves have incurred high extinction rates due to human-induced mortality on surrounding private lands.

Table 2. Descriptions of the Heartland parks included in analysis.

Park Name and Abbreviation		Location and Area	Significant Ecosystems
Buffalo National River	BUFF	95,730 ac (38, 757 ha) in the Ozark Highlands of north-central Arkansas	Upland and riparian hardwood forest; Buffalo River; caves
Cuyahoga Valley National Park	CUVA	32,943 ac (13,332 ha) in northeastern Ohio, between Cleveland and Akron	Upland and riparian hardwood forest; Cuyahoga River
Herbert Hoover National Historic Site	HEHO	186 ac (75 ha) in east-central Iowa	Restored tallgrass prairie and fields; Hoover Creek
Hot Springs National Park	HOSP	5,549 ac (2,247 ha) in the Oauachita Mountains of central Arkansas	Thermal spring waters; upland hardwood forest
Lincoln Boyhood National Memorial	LIBO	200 ac (81 ha) in southwestern Indiana	Upland and lowland mesic hardwood forest
Ozark National Scenic Riverways	OZAR	80, 790 ac (32,709 ha) of the Ozark Highlands in southeastern Missouri	Upland and riparian hardwood forest; Jack's Fork and Current Rivers
Pea Ridge National Military Park	PERI	4,300 ac (1,741 ha) in the extreme northwest corner of Arkansas	Upland hardwood forest; fields

Table 3. Spatial datasets used for characterization of current landscape and land use change over time.

Spatial Dataset	Source	Source Location	Measure	Scale
Housing and population density	U.S. Census Bureau (2000)	www.census.gov	Average number per square mile	County
Water discharge permit records	State (AR, MO, IA, IN, OH, KY) Departments' of Environmental Quality; U.S. EPA (2003)	www.epa.gov/enviro/	Number of industrial (NPDES) water discharge sites	County
Land cover	USGS, National Land Cover Dataset (1992)	http://edc.usgs.gov	Land cover classified into cover types depicting industrial, urban, wetlands, shrub, pasture, crops, and forest. Percent of each land cover type measured as % of total pixels.	30 meter pixel
Conventional water pollution	EPA National Watershed Characterization (1999)	www.epa.gov/iwi/	Percent of time water samples exceed non-toxic (nutrients, total suspended solids, biochemical oxygen, etc.) pollutant limits	Watershed
Hydrologic modification	EPA National Watershed Characterization (1999)	www.epa.gov/iwi/	Relative degree of modification based on reservoir storage capacities of existing dams (at least 50 feet tall)	Watershed
Cities	National Atlas of the United States (2000)	www.nationalatlas.gov	Cities (with at least 1000 people) by population size	City
Overall population change	U.S. Census Bureau (1950 -2000)	www.census.gov	Percent population growth	County
Change in farmland acreage	U.S. Census of Agriculture (1950 – 1997); State (MO, IA, IN, OH, KY) Agriculture Statistics Services	www.nass.usda.gov/census/ http://agebb.missouri.edu www.nass.usda.gov/ia/ www.nass.usda.gov/in/ www.nass.usda.gov/ky/ 1950 Census of Agriculture (Published by U.S. Census Bureau-Ag. Division, by state)	Percent change in "acres in farms"	County
Trends in major dam construction	U.S. Army Corp of Engineers and FEMA, National Inventory of Dams (1996)	www.nationalatlas.gov	Number of major dams built per decade, based on extrapolation from "date of construction"	Individual dam
Change in housing density	U.S. Census Bureau, "Profile of Selected Housing Characteristics" (2000)	www.census.gov	Number of houses built per decade from 1950-2000, based on extrapolation from "Year Structure Built" category	County

Table 4. Counties and watersheds (USGS Hydrologic Cataloging Unit) included for each park in land use characterization and change analysis

Park	State	Counties	USGS Watersheds
BUFF	Arkansas	Baxter*, Boone, Carroll, Madison, Marion*, Newton*, Pope, Searcy*, Stone	11010001, 11010003, 11010004, 11010005*, 11010014, 11110201, 11110202
CUVA	Ohio	Cuyahoga*, Geauga, Medina, Portage, Stark, Summit*	04110001, 04110002*, 04110003, 04110004, 05030103, 05040001
HEHO	Iowa	Cedar*, Johnson, Jones, Linn, Louisa, Muscatine, Washington	07080101, 07080102, 07080103, 07080205, 07080206*, 07080208, 07080209
HOSP	Arkansas	Clark, Garland*, Hot Spring, Montgomery, Perry, Saline	08040101*, 08040102, 08040103, 08040203, 11110105, 11110206, 11140108, 11140109
LIBO	Indiana	Dubois, Gibson, Perry, Pike, Spencer*, Warrick, Daviess (KY), Hancock (KY)	05110004, 05110005, 05120209, 05140104, 05140201*, 05140202
OZAR	Missouri	Butler, Carter*, Dent*, Howell, Oregon, Reynolds, Ripley, Shannon*, Texas*, Clay (AR), Randolph (AR)	07140102, 10290202, 10290203, 11010006, 11010007, 11010008*, 11010009, 11010011
PERI	Arkansas	Benton*, Carroll, Madison, Washington, Barry (MO), McDonald (MO), Newton (MO)	11010001, 11010002, 11070206, 11070207, 11070208*, 11070209, 11110103

*County or watershed where park is located

Table 5. Proportion of current (early 1990's) land cover types represented in each park landscape.

Park	**Land Cover Type** **Natural** (forest, shrub, wetlands)	 **Agriculture** (row crops, pasture/hay)	 **Urban** (industrial, high and low intensity urban, bare ground)
BUFF	75%	24%	1%
CUVA	41%	38%	21%
HEHO	13%	82%	5%
HOSP	86%	12%	1%
LIBO	32%	64%	3%
OZAR	67%	32%	.5%
PERI	51%	47%	2%

Table 6. Results of current landscape characterization analysis for each park.

Park	Population density (2000)	Housing density (2000)	Presence of industrial discharge sites (2003)	Conventional water quality score (mid-1990's)	Hydrologic modification score (mid-1990's)
CUVA	980	418	1 per 20 mi²	2.3	2.2
OZAR	23	11	1 per 53 mi²	1.2	1.8
BUFF	35	16	1 per 874 mi²	1.4	2.6
PERI	88	37	1 per 62 mi²	2.1	2.4
HEHO	106	44	1 per 59 mi²	2.3	1.7
LIBO	90	37	1 per 17 mi²	1.7	2.5
HOSP	58	26	1 per 211 mi²	1.5	2.8

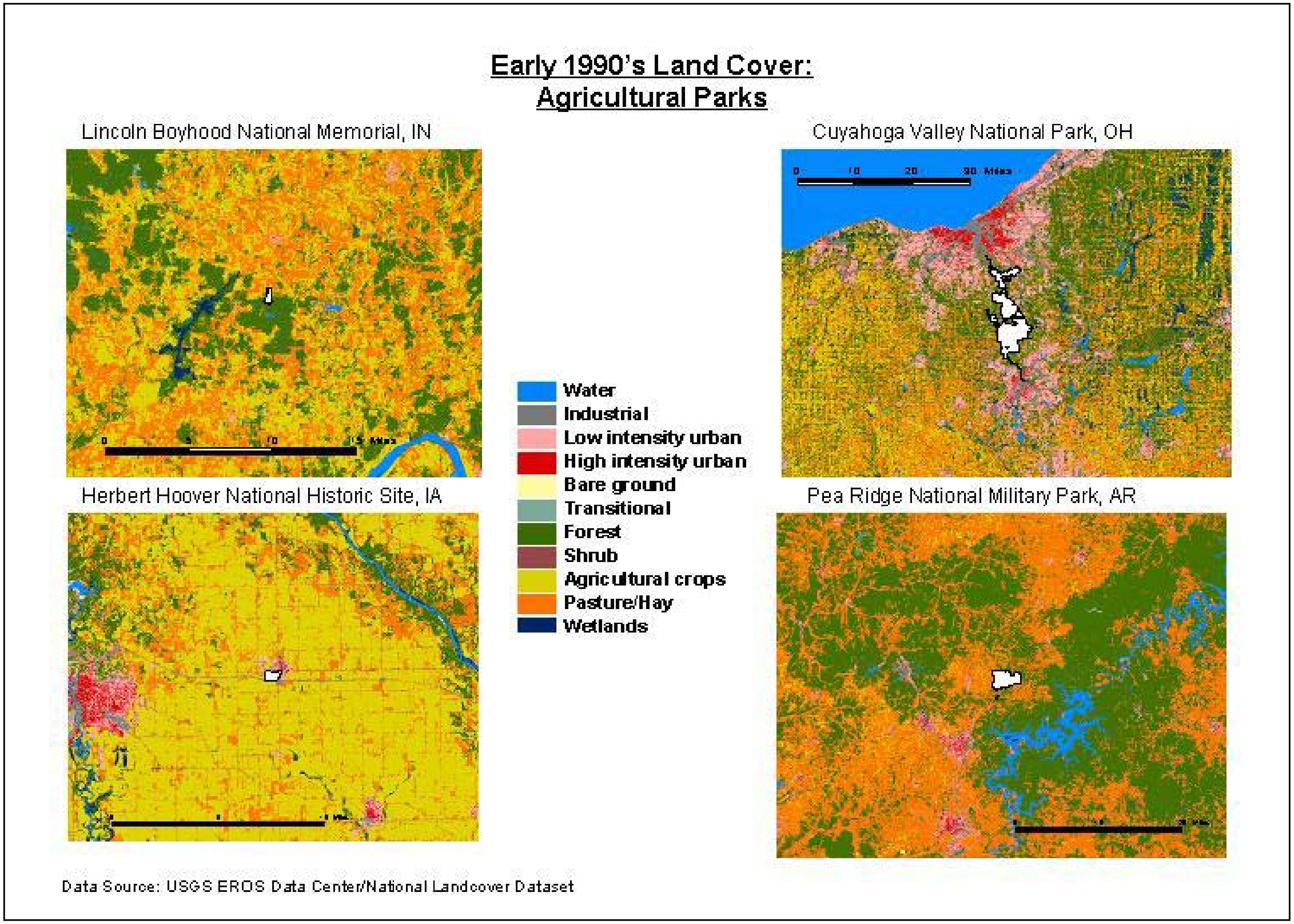
Table 7. Results of change over time analysis for each park.

Park	Percent change in housing density (houses/mi²) 1950-2000	Absolute change in housing density (houses/mi²) 1950-2000	Percent change in population density (people/mi²) 1950-2000	Absolute change in population density (people/mi²) 1950-2000	Percent change in farmland acreage 1950-1997
CUVA	+173 %	+262	+22 %	+179	-61 %
OZAR	+442 %	+9	+11 %	+2	-18 %
BUFF	+746 %	+14	+89 %	+16	-26 %
PERI	+637 %	+32	+159 %	+54	-24 %
HEHO	+250 %	+31	+67 %	+42	-14 %
LIBO	+339 %	+28	+47 %	+29	-22 %
HOSP	+745 %	+23	+90 %	+28	-51 %

Table 8. Possible indicators for monitoring land use change over time.

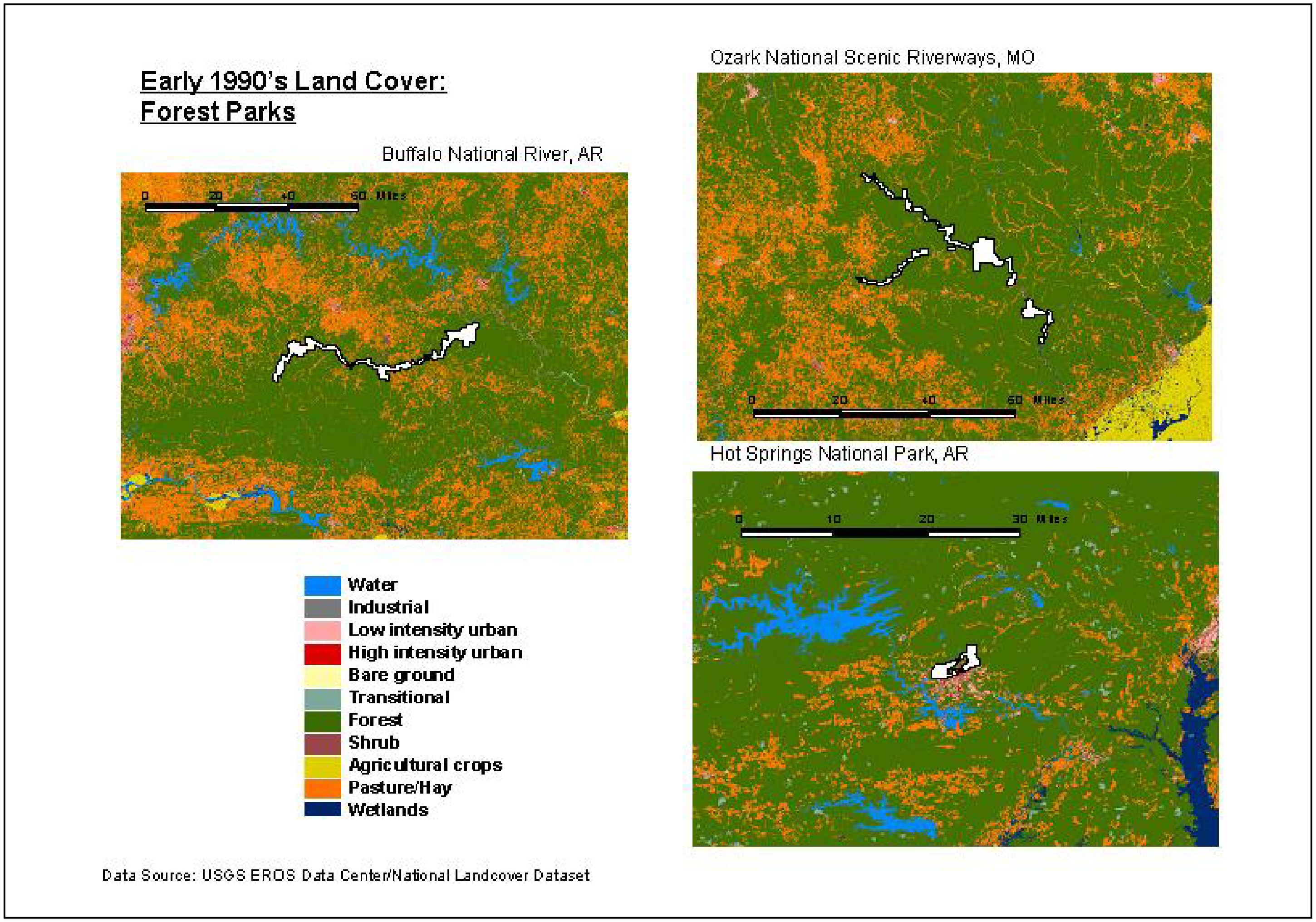
Category	Variables	Source	Spatial Scale	Method	Analysis
Land cover/use	Urban, Agricultural, and Natural cover types	USGS National Land Cover Dataset	30 meter pixel	Acquire maps from USGS every five to ten years	Trajectories of change by cover type
	Urban, Agricultural, and Natural cover types	Landsat Thematic Mapper	30 meter pixel	Statistical image classification, based on air photo reference data; obtain every one or two years	Trajectories of change by cover type
Land use/ Demography	Housing density	County Tax Assessor	Township, Range, Section	Obtain annually for each county, digitize as necessary	Summarize change surrounding park overall, and where changing most
	Housing density	US Census Bureau	Census block group	Obtain decadally for each county, digitize as necessary	Summarize change surrounding park overall, and where changing most
Demography	Population density	US Census Bureau	County or Census block group	Obtain annually per county or every ten years per block group	Summarize change by county
Wildlife populations	Occurrence and abundance of breeding birds	USGS North American Breeding Bird Survey	Level III Ecoregion (Omernick 1987)	Acquire annually from USGS survey results for local BBS routes	Summarize trends in abundance of species or groups of species over time
Hydrologic flow regime	Stream stage, Streamflow	USGS real-time hydro-gauge stations	Gauge station; watershed	Acquire hydrologic measurements daily from regional gauges	Summarize daily and seasonal trends in hydrologic flows
Physical aquatic surveys: Water quality	Nutrients, pesticides, temperature, pH, oxygen	USGS National Water Quality Assessment	Water quality station; watershed or basin	Obtain data approx. every ten years for each station	Summarize trends in abundance of certain variables of concern
	Variable	Local and state agencies as reported to EPA STORET	Water quality station; watershed	Obtain data monthly or annually for each station	Summarize trends in abundance of certain variables of concern
Biological aquatic surveys: Aquatic populations	Fish, Invertebrates, Algae	USGS National Water Quality Assessment	Data station; watershed or basin	Obtain data approx. every ten years for each station	Summarize trends in abundance of native and exotic species

Figure 1a. Early 1990’s land cover for Heartland agricultural parks.



Data Source: USGS EROS Data Center/National Landcover Dataset

Figure 1b. Early 1990’s land cover for Heartland forest parks.



Data Source: USGS EROS Data Center/National Landcover Dataset

Figure 2. Proportion of each land cover type within landscapes surrounding Heartland parks in the early 1990's.

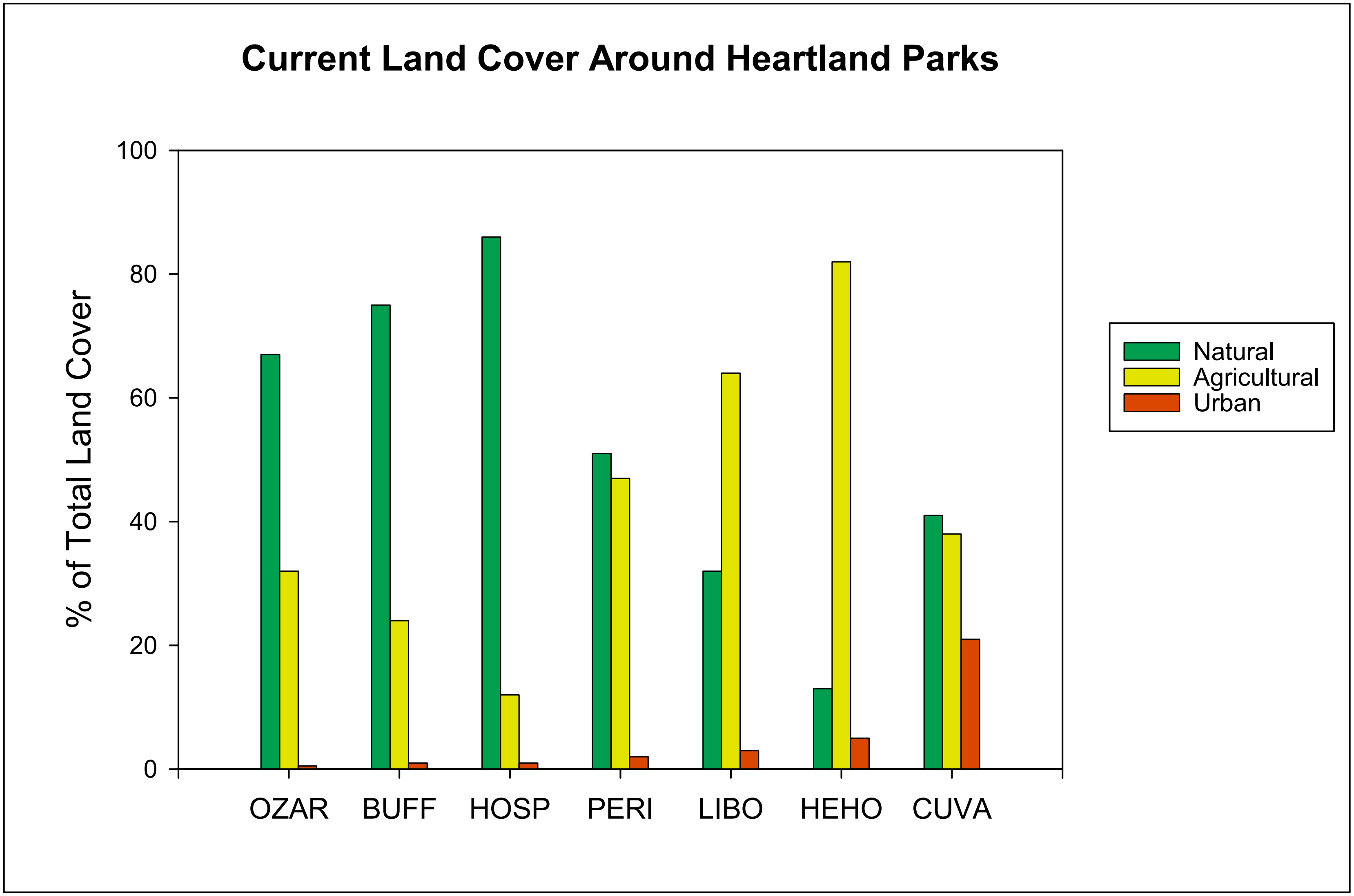
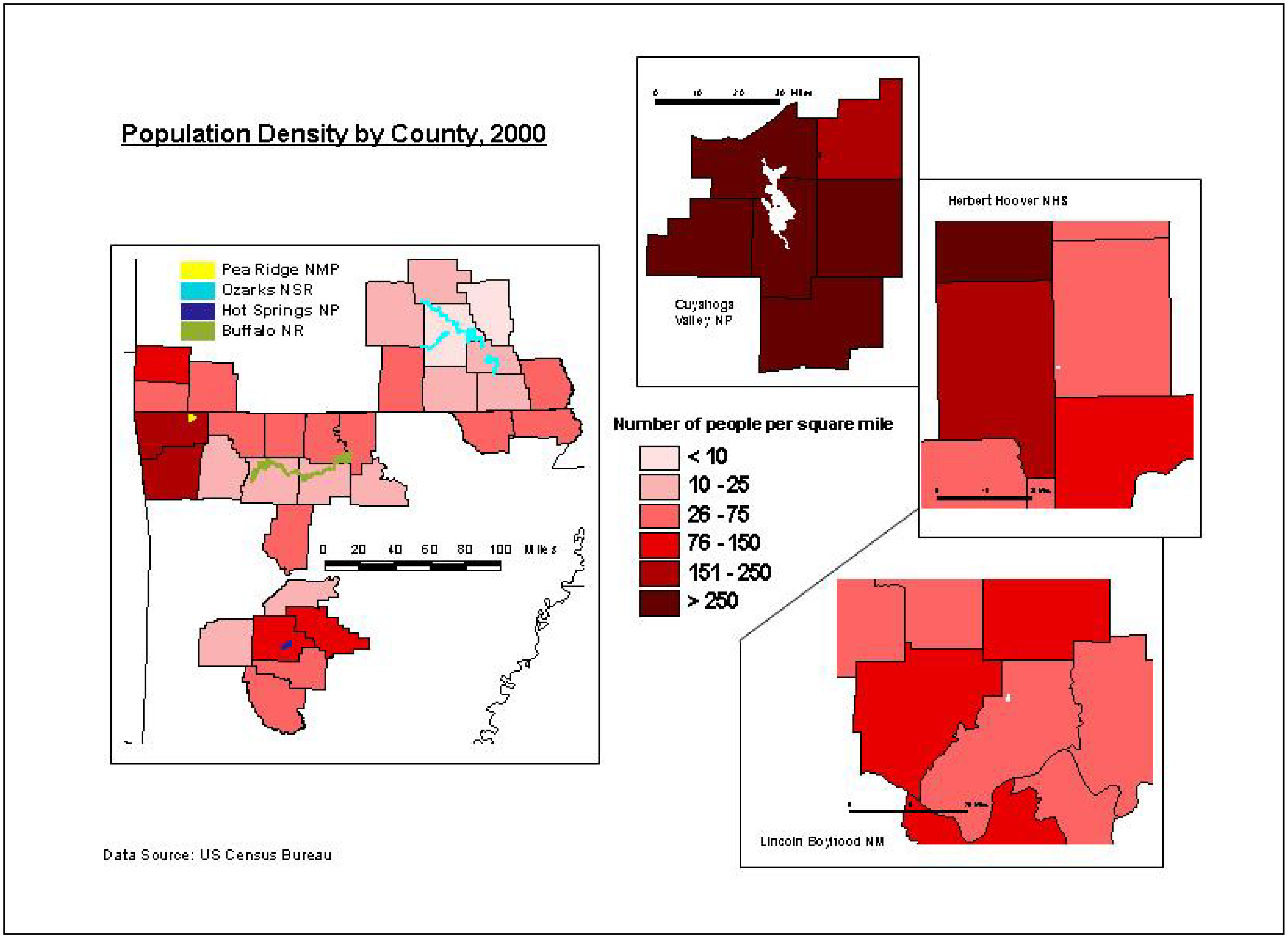


Figure 3. Population density for the year 2000 for counties surrounding Heartland parks.



Data Source: US Census Bureau

Figure 4. Average housing densities within counties surrounding Heartland parks in the year 2000.

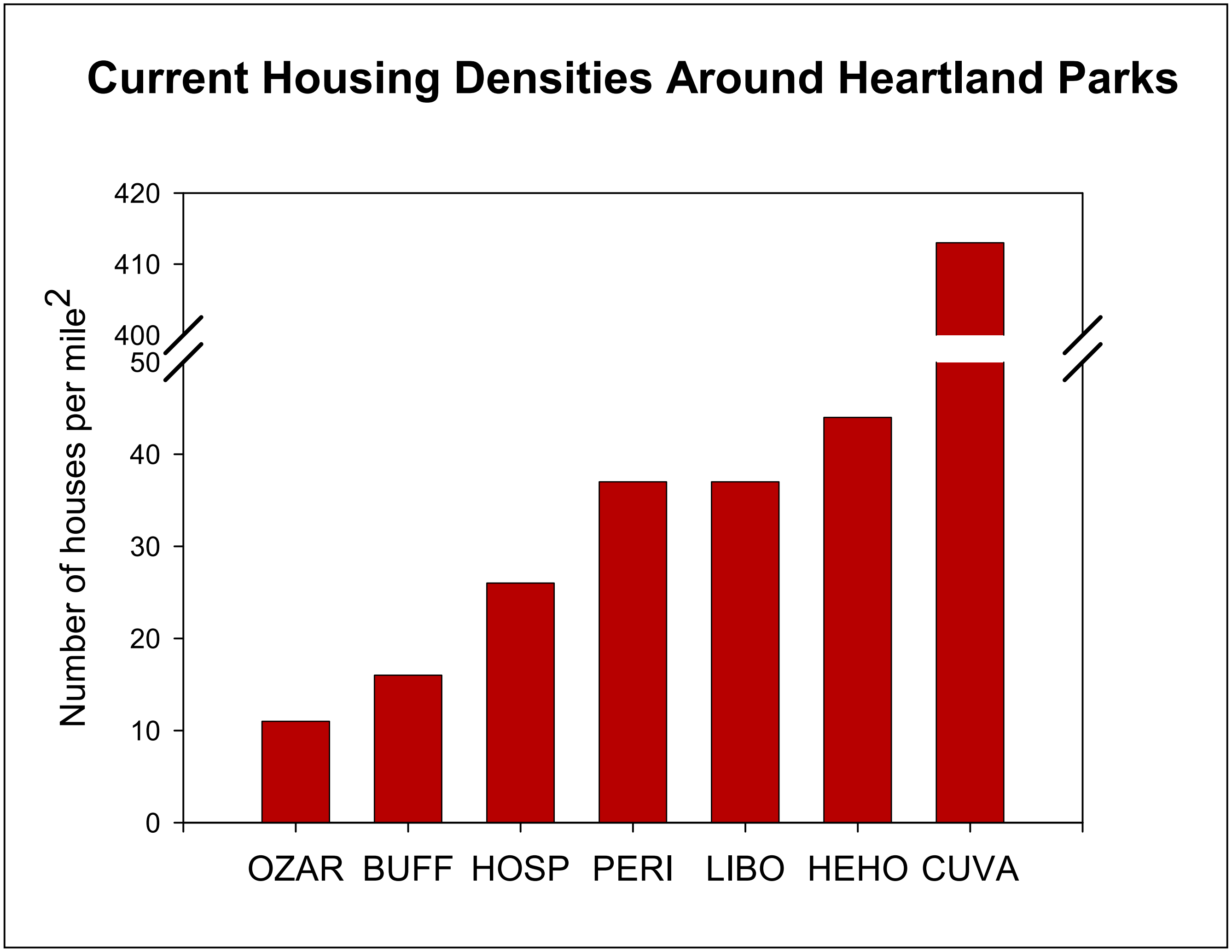
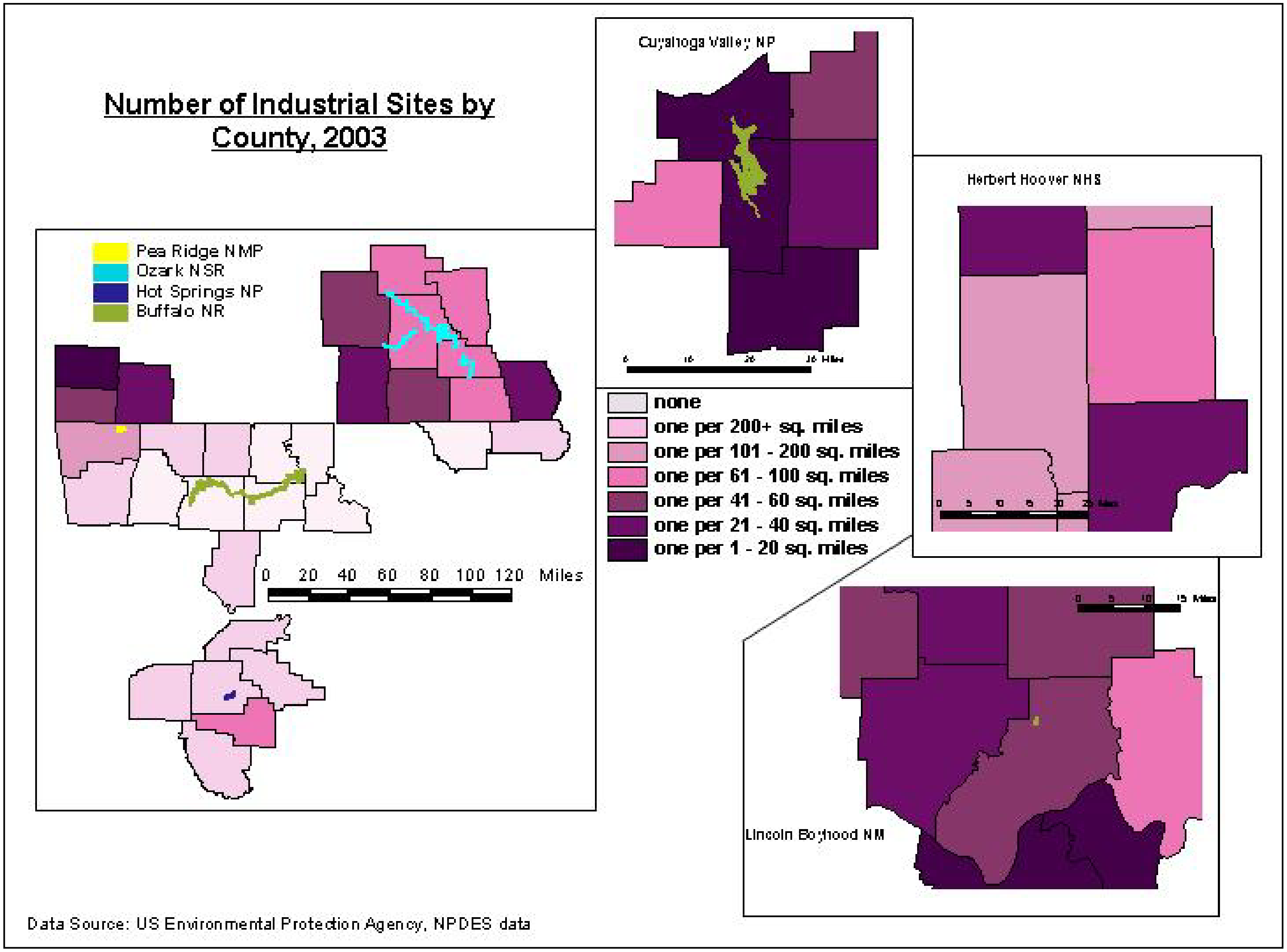
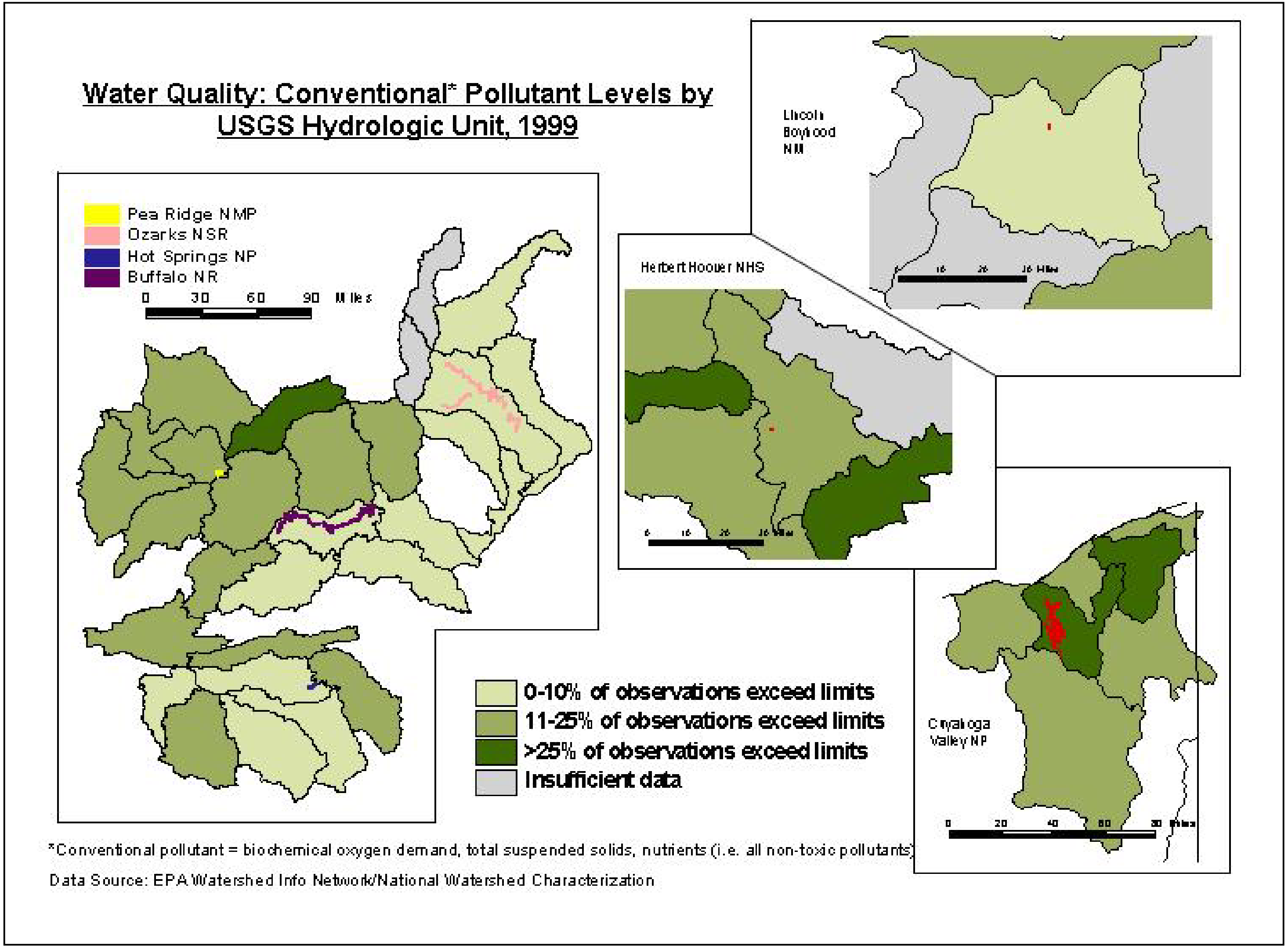


Figure 5. Measure of industry within counties surrounding Heartland parks in 2003.



Data Source: US Environmental Protection Agency, NPDES data

Figure 6. Measure of water quality within watersheds surrounding Heartland parks in the early 1990s.

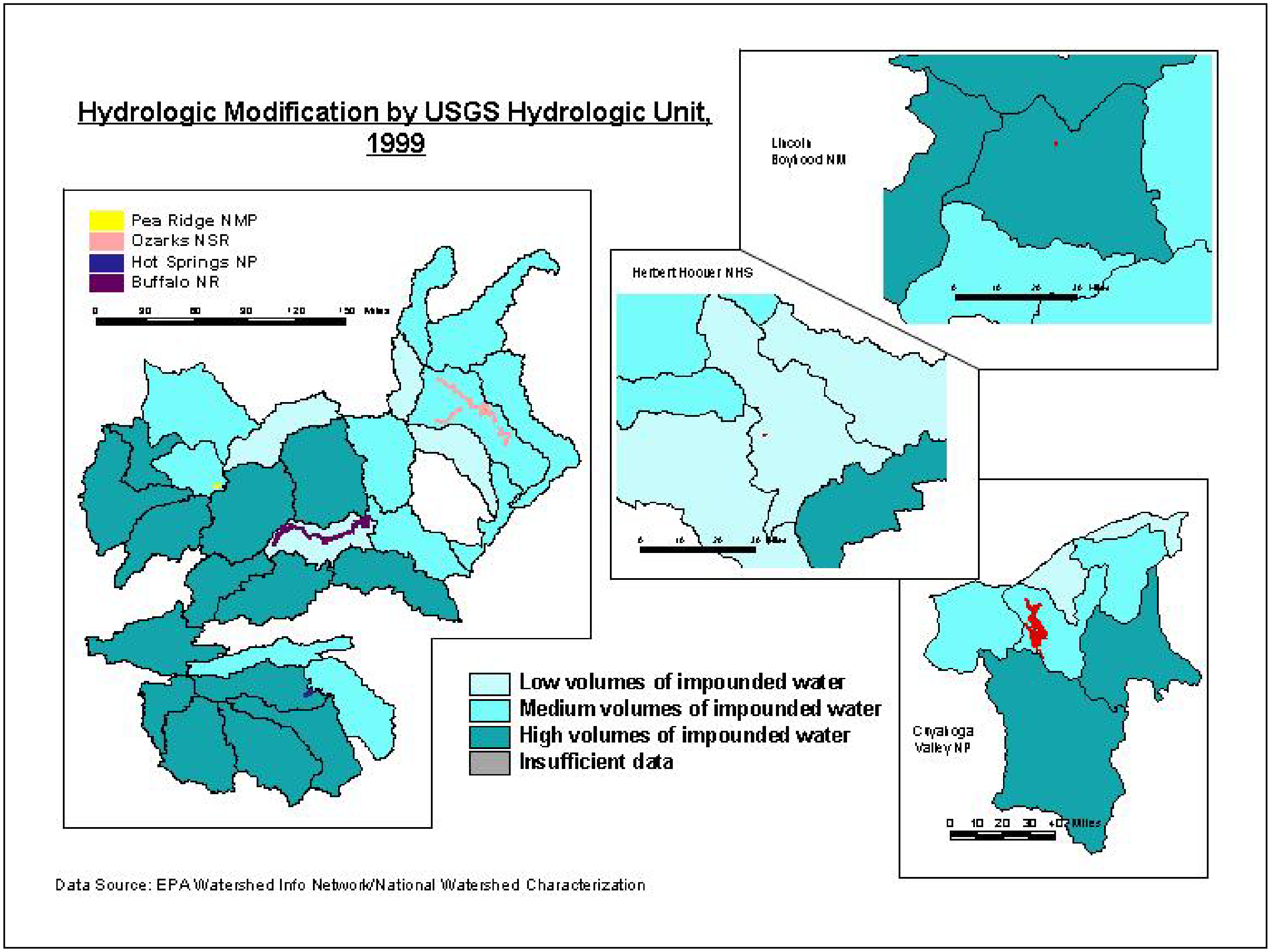


Water Quality: Conventional* Pollutant Levels by USGS Hydrologic Unit, 1999

*Conventional pollutant = biochemical oxygen demand, total suspended solids, nutrients (i.e. all non-toxic pollutants)

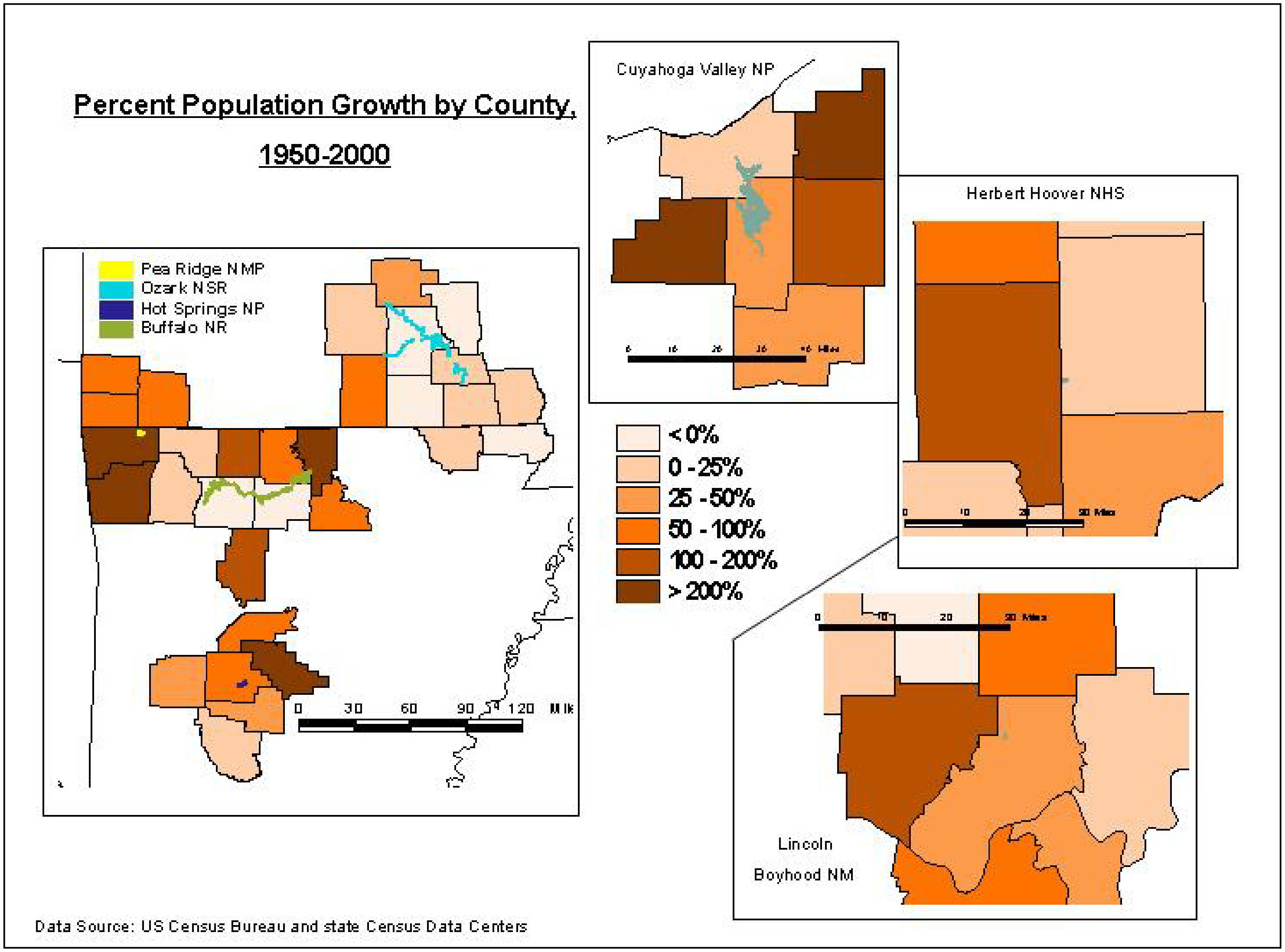
Data Source: EPA Watershed Info Network/National Watershed Characterization

Figure 7. Measure of hydrologic modification within watersheds surrounding Heartland parks in 1999.



Data Source: EPA Watershed Info Network/National Watershed Characterization

Figure 8. Population growth within counties surrounding Heartland parks.



Data Source: US Census Bureau and state Census Data Centers

Figure 9. Increase in housing density over time within Heartland parks.

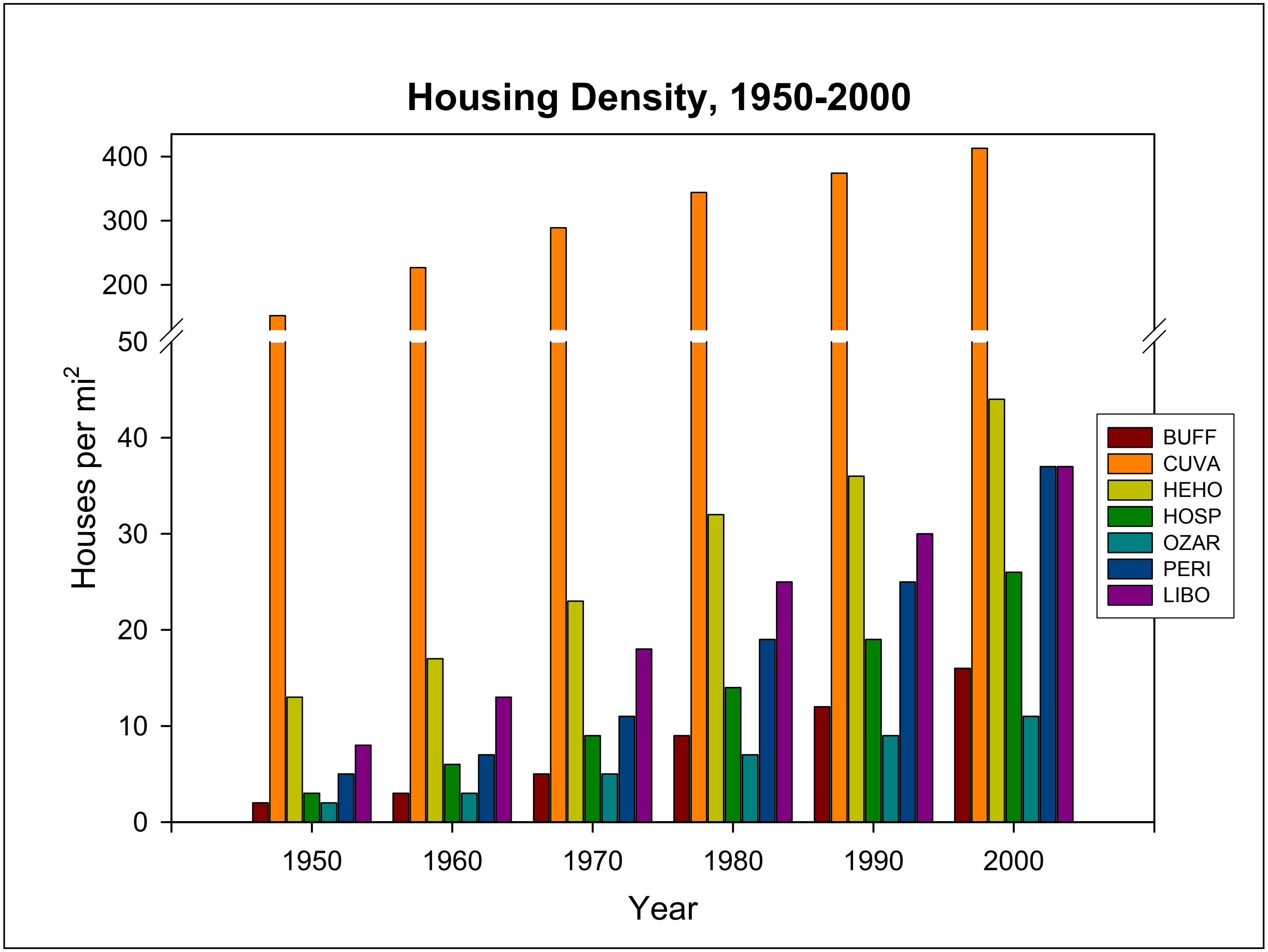


Figure 10. Number of dams built on waterways within the HTLN from 1950 to 1996.

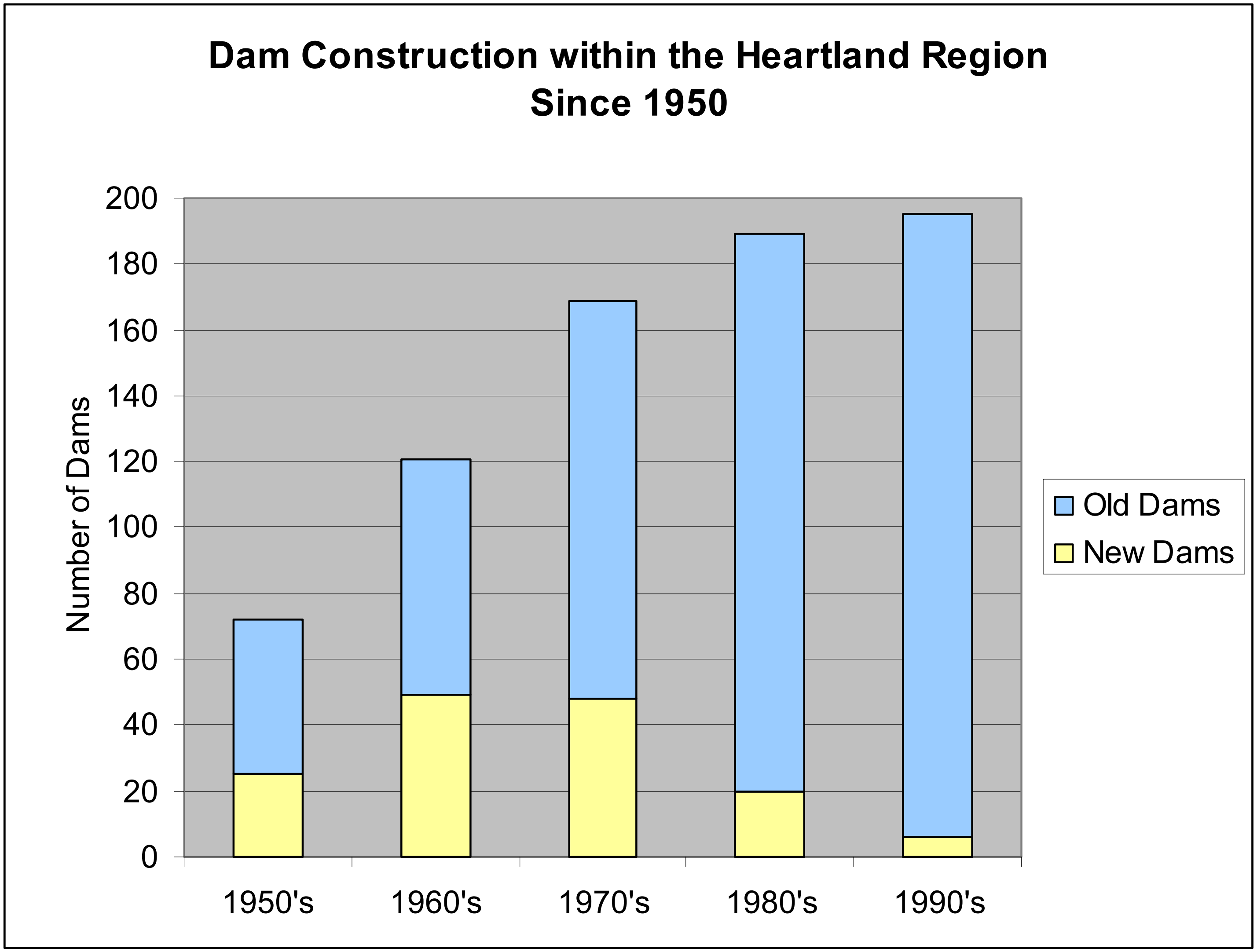
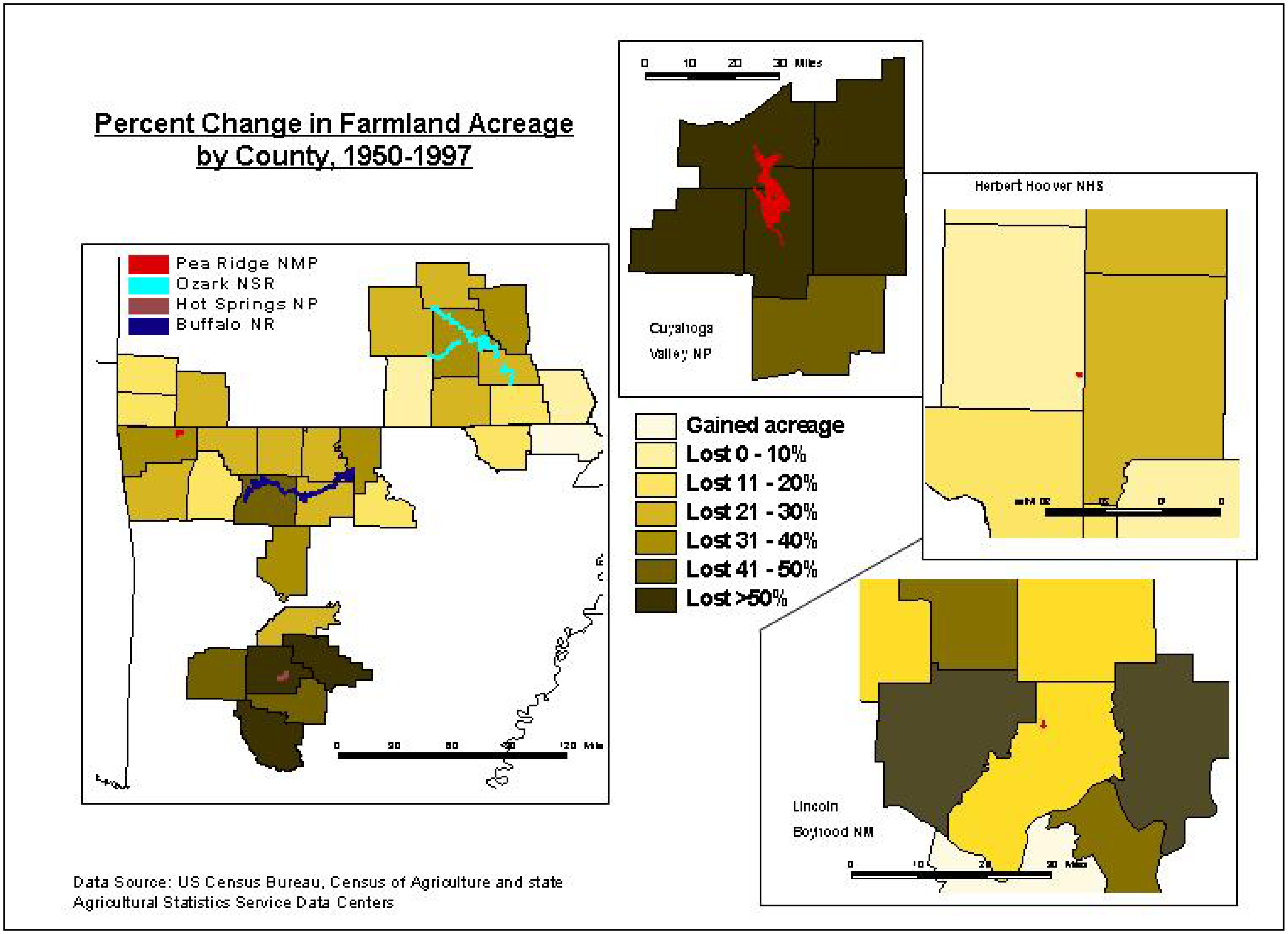


Figure 11. Loss in farmland acreage over time within counties surrounding Heartland parks.



Data Source: US Census Bureau, Census of Agriculture and state Agricultural Statistics Service Data Centers

Figure 12. Decline in the amount of farmland acreage surrounding Heartland parks and the region as a whole.

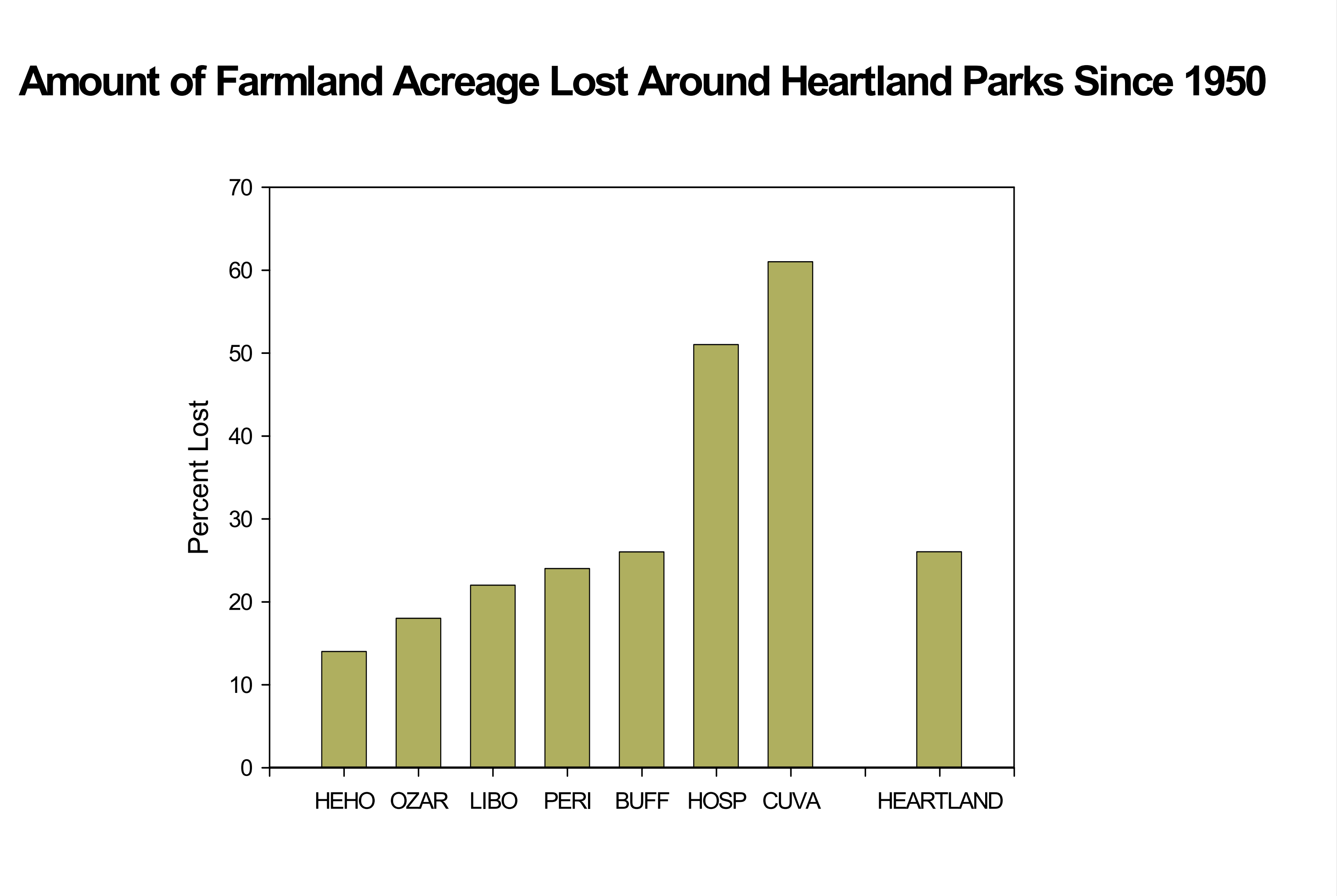


Figure 13. Average scores of conventional water pollution and hydrologic modification for watersheds surrounding Heartland parks in the late 1990's.

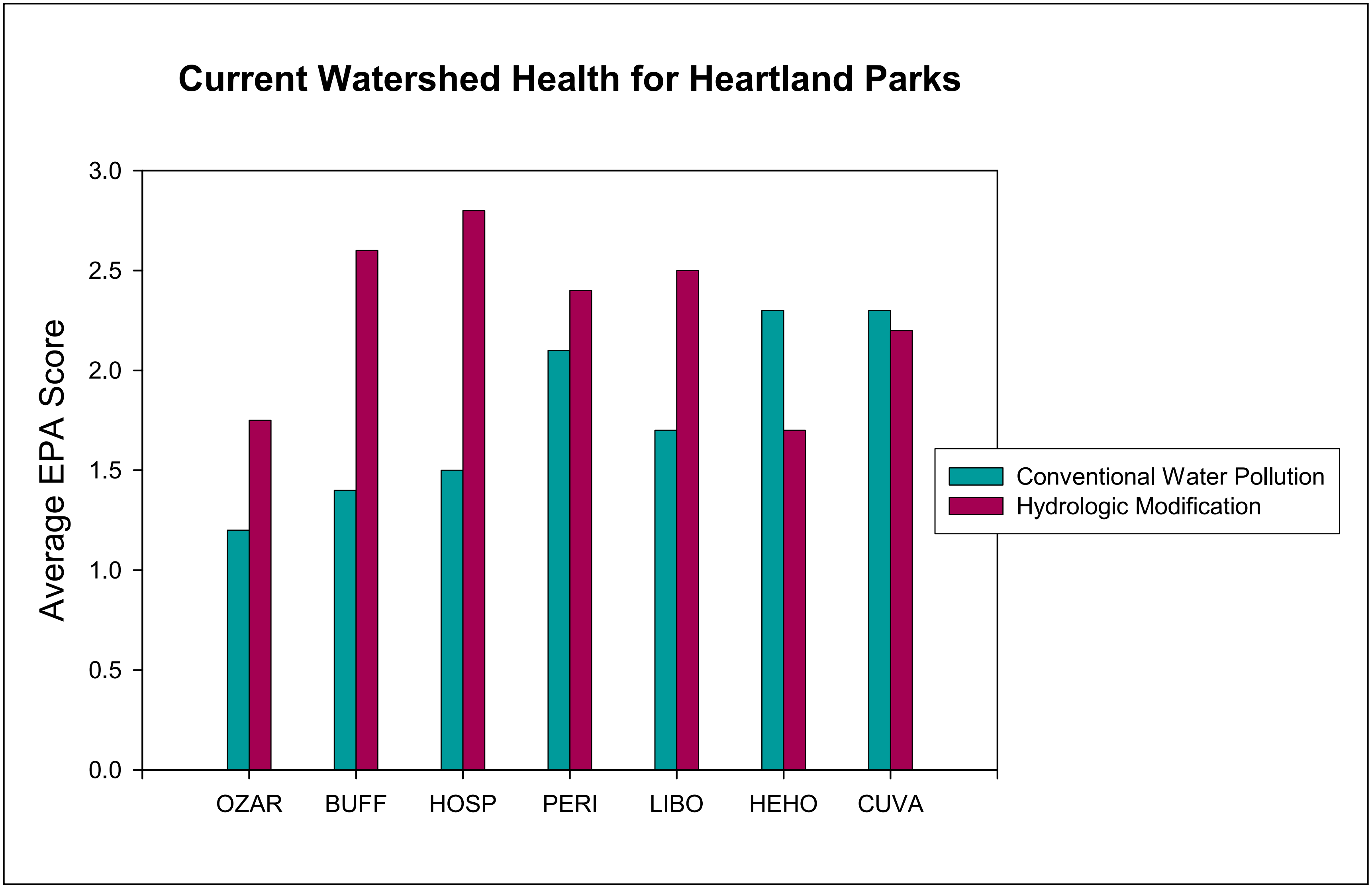


Figure 14. Diagram depicting large scale influences and linkages between land use change disturbance and ecological mechanisms (stressors).

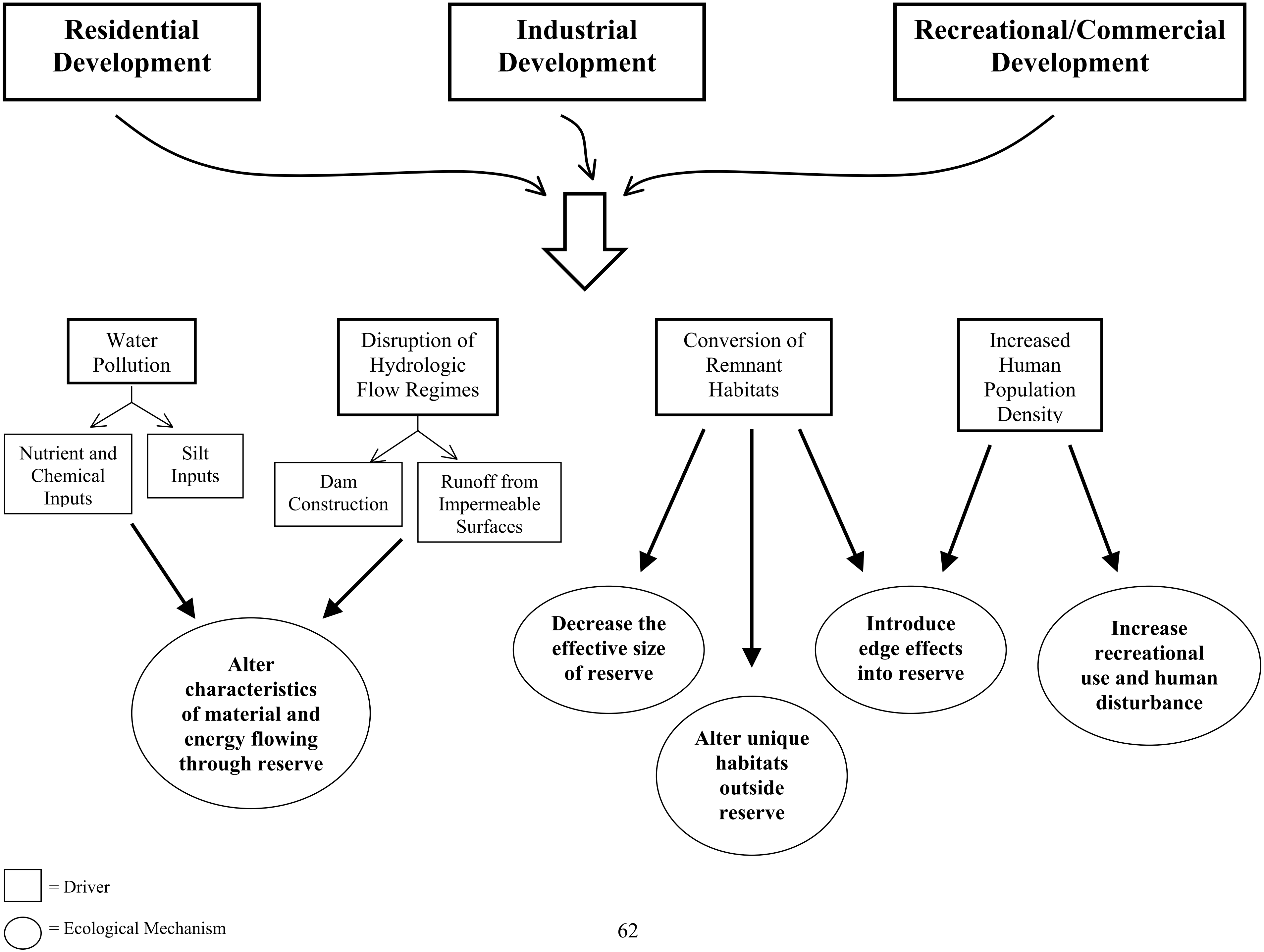


Figure 15a. Conceptual model diagram showing relationships between specific drivers and ecological functioning.

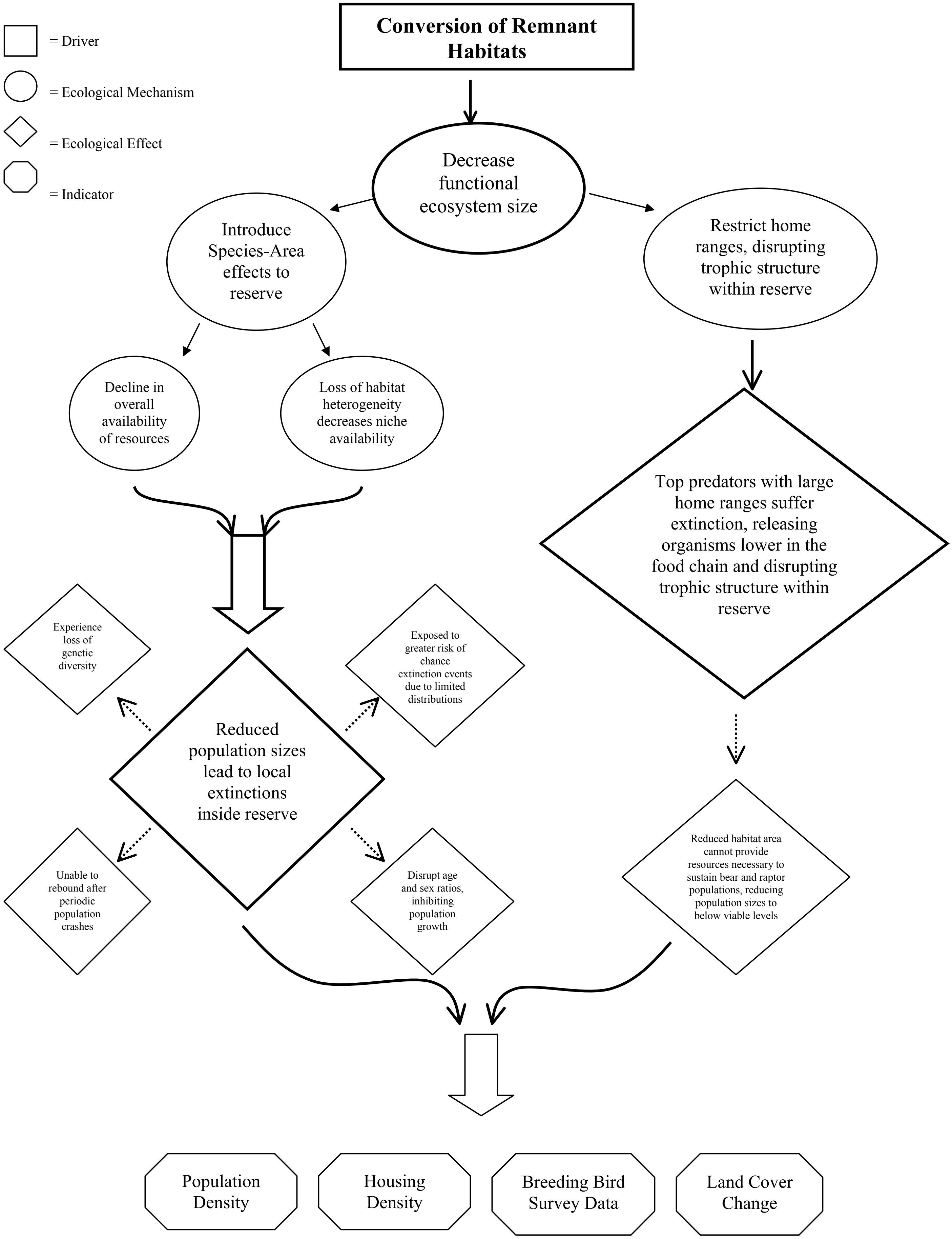


Figure 15b. Conceptual model diagram showing relationships between specific drivers and ecological functioning.

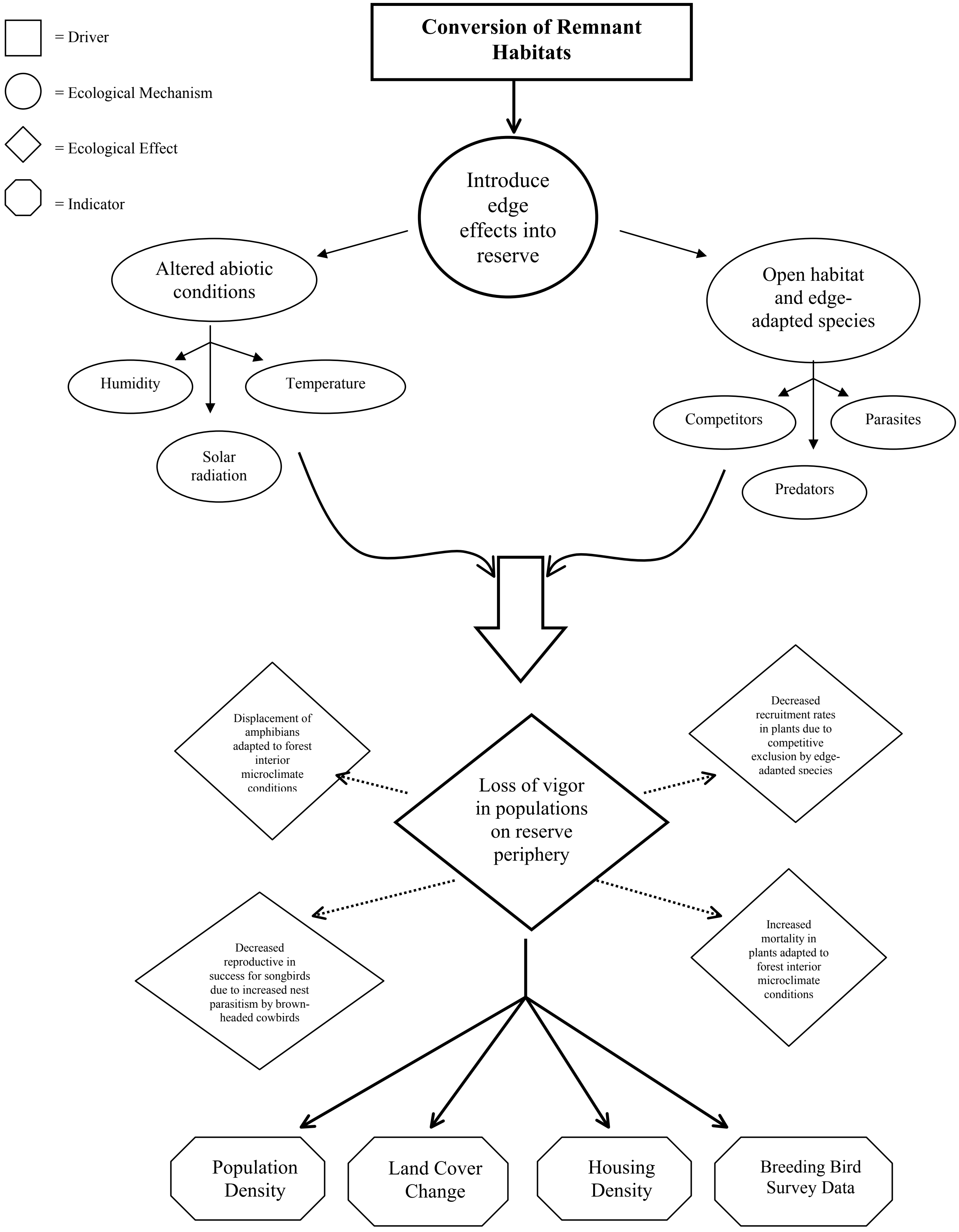


Figure 15c. Conceptual model diagram showing relationships between specific drivers and ecological functioning.

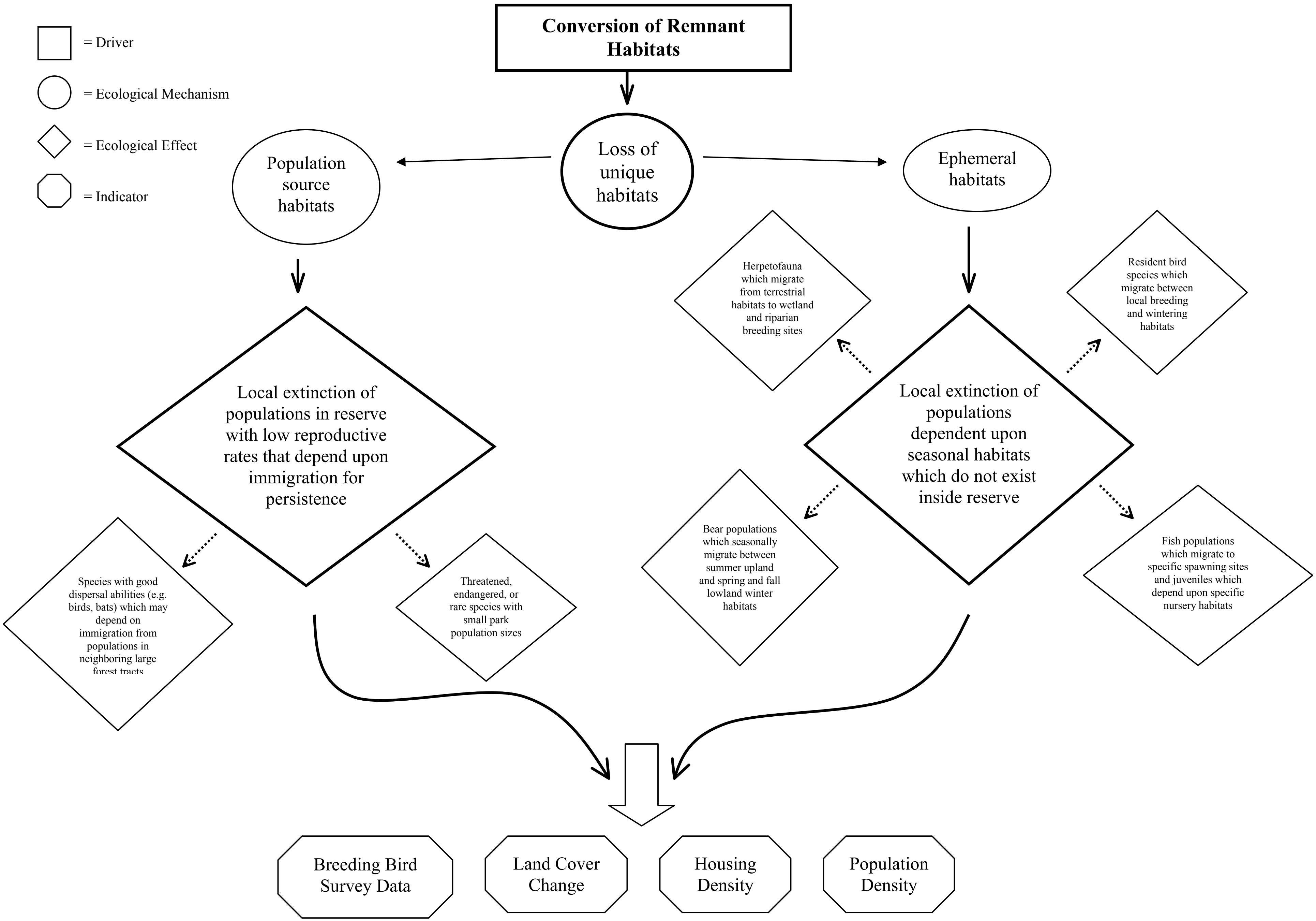


Figure 15d. Conceptual model diagram showing relationships between specific drivers and ecological functioning.

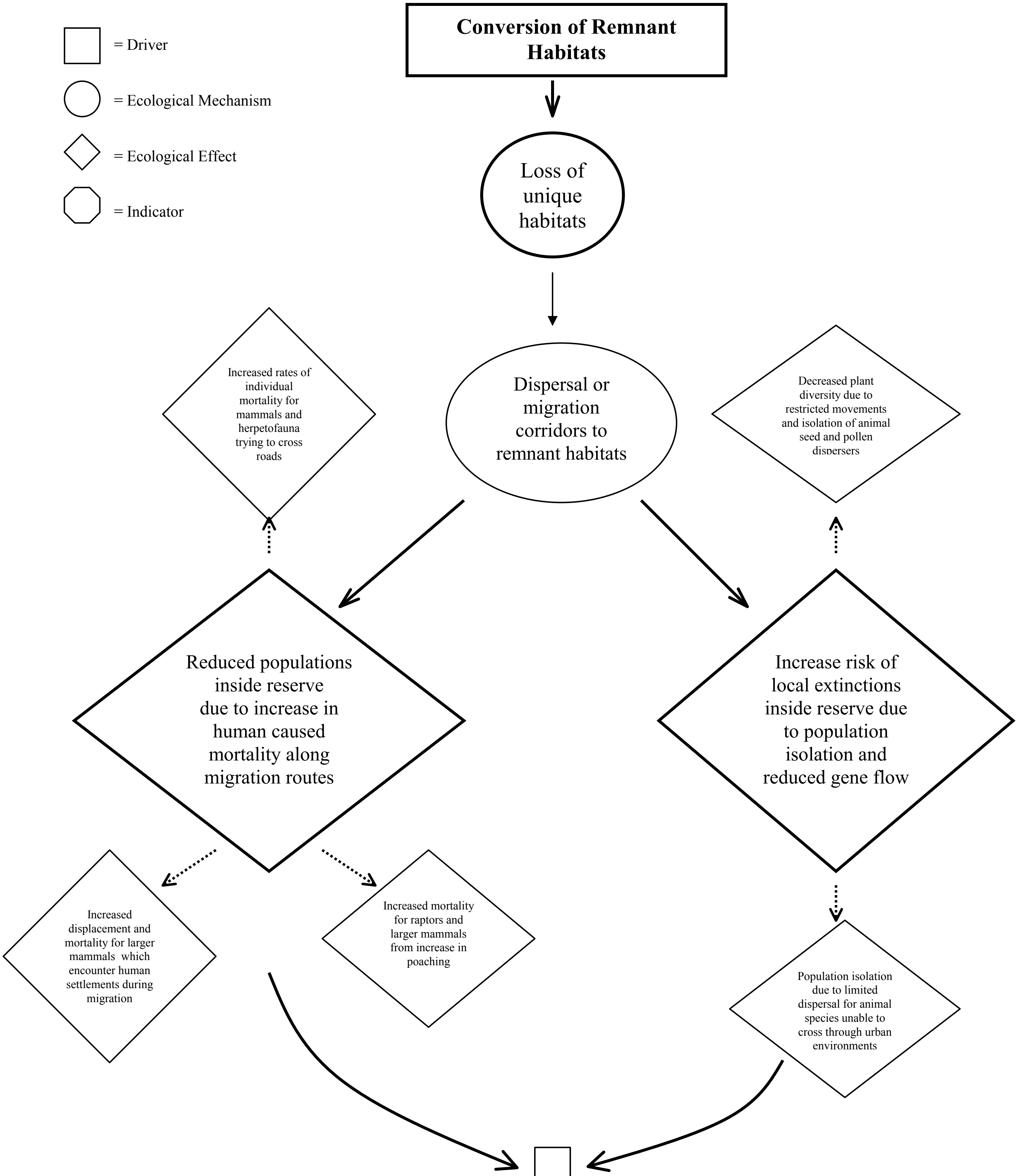
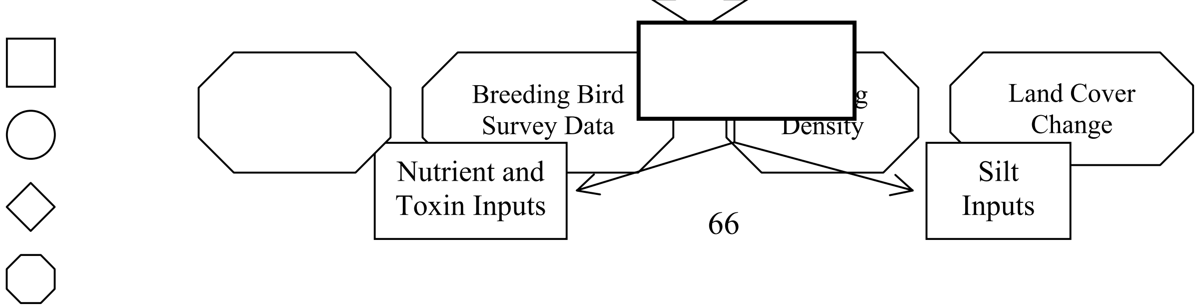


Figure 15e. Conceptual model diagram showing relationships between specific drivers and ecological functioning.



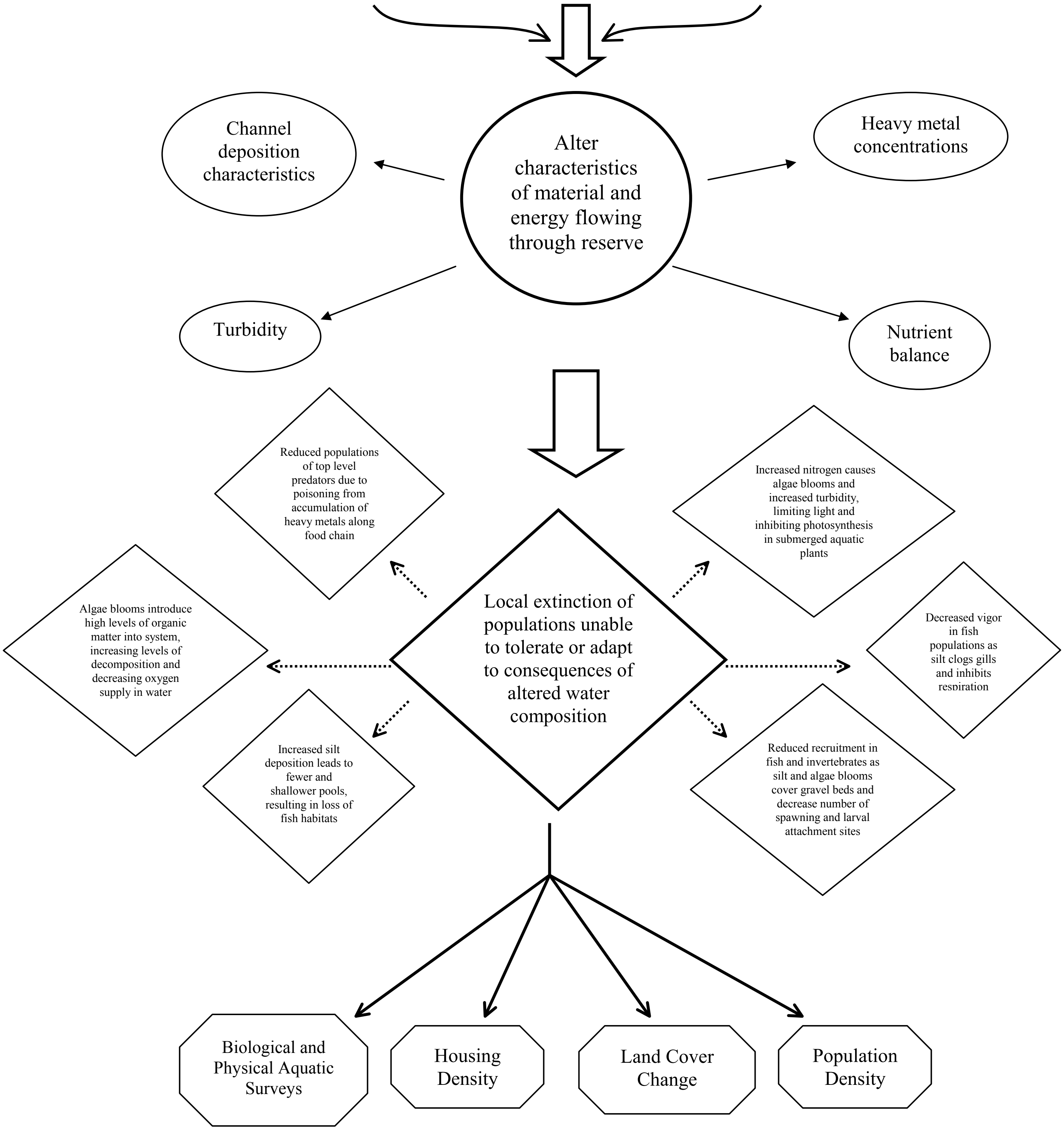

Alter characteristics of material and energy flowing through reserve
Channel deposition characteristics
Heavy metal concentrations
Turbidity
Nutrient balance
Reduced populations of top level predators due to poisoning from accumulation of heavy metals along food chain
Increased nitrogen causes algae blooms and increased turbidity, limiting light and inhibiting photosynthesis in submerged aquatic plants
Algae blooms introduce high levels of organic matter into system, increasing levels of decomposition and decreasing oxygen supply in water
Local extinction of populations unable to tolerate or adapt to consequences of altered water composition
Decreased vigor in fish populations as silt clogs gills and inhibits respiration
Increased silt deposition leads to fewer and shallower pools, resulting in loss of fish habitats
Reduced recruitment in fish and invertebrates as silt and algae blooms cover gravel beds and decrease number of spawning and larval attachment sites
Biological and Physical Aquatic Surveys
Housing Density
Land Cover Change
Population Density

Figure 15f. Conceptual model diagram showing relationships between specific drivers and ecological functioning.

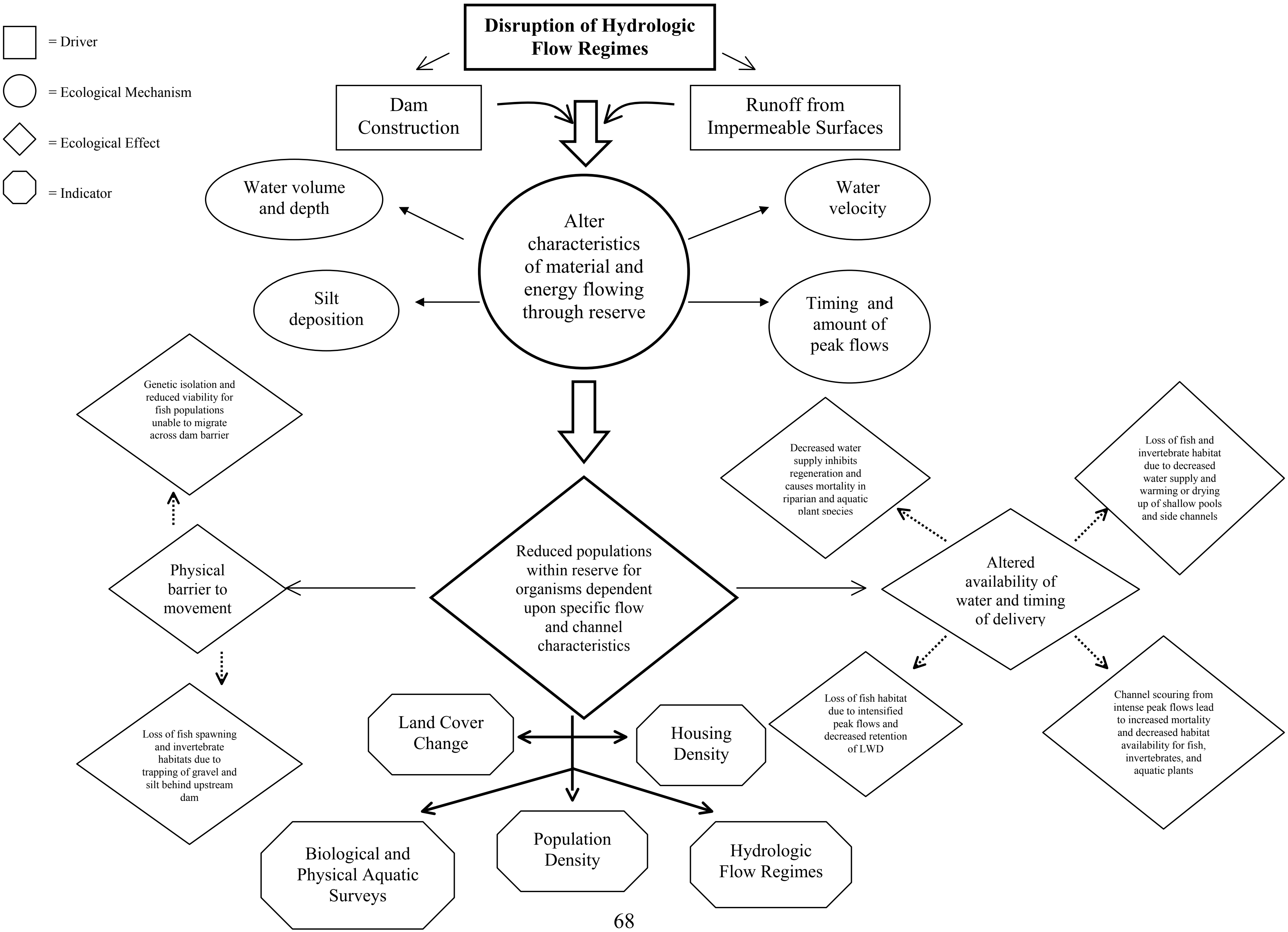


Figure 15g. Conceptual model diagram showing relationships between specific drivers and ecological functioning.

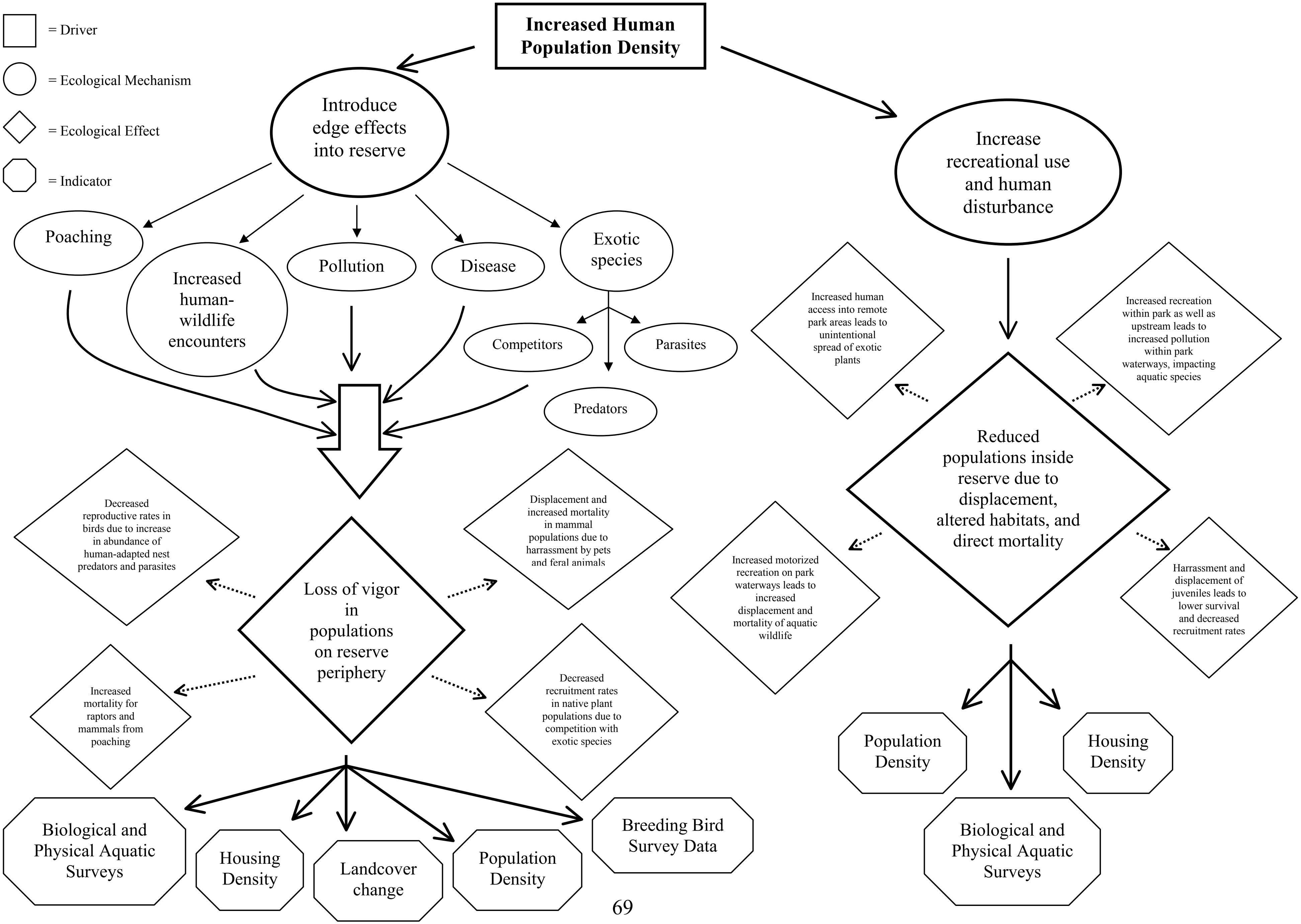


Figure 16. Example of census block groups for quantifying future housing and population density within counties surrounding Hot Springs National Park

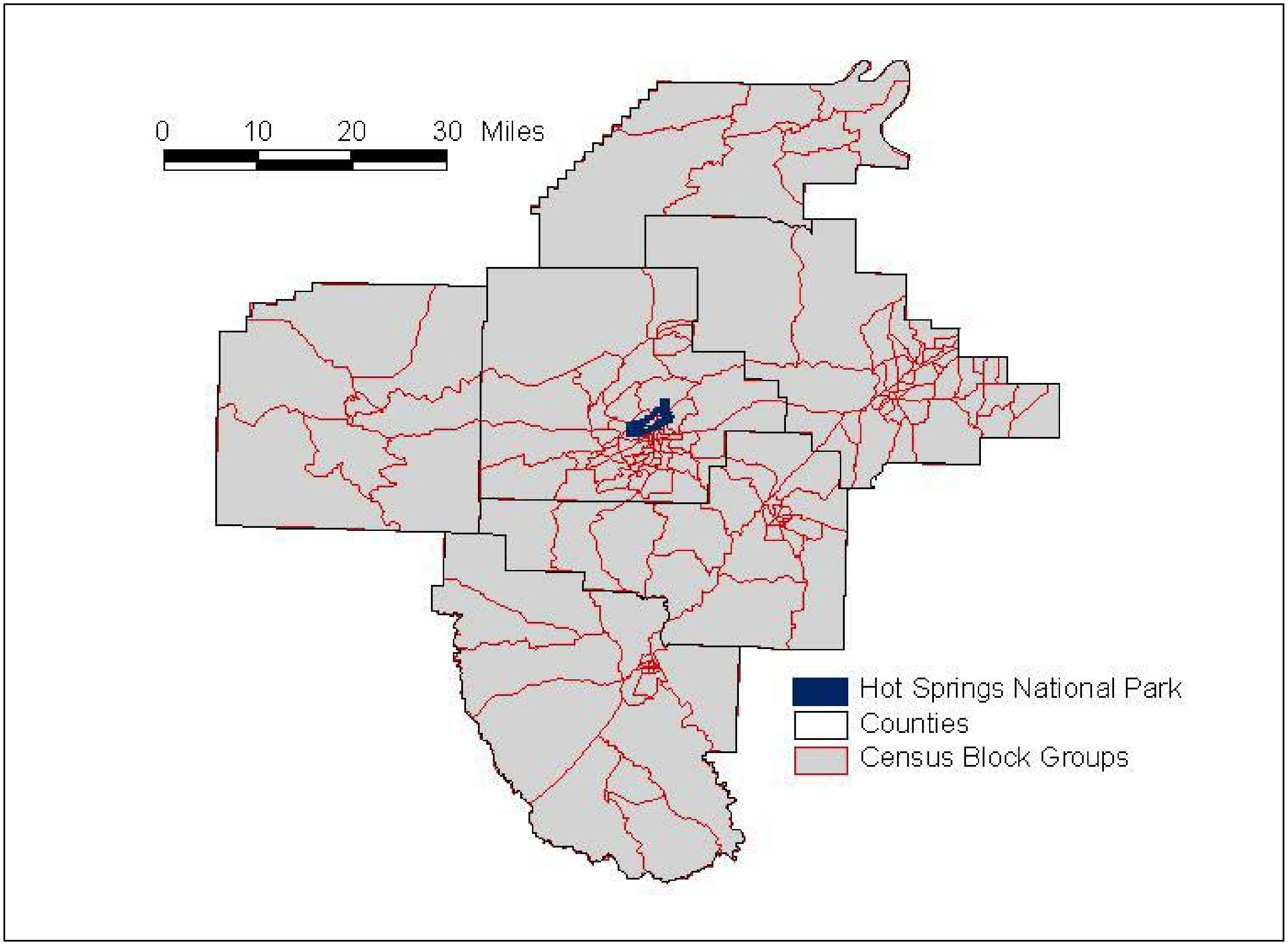


Figure 17. Comparison between county-defined park study areas and ecoregions for monitoring BBS trends.

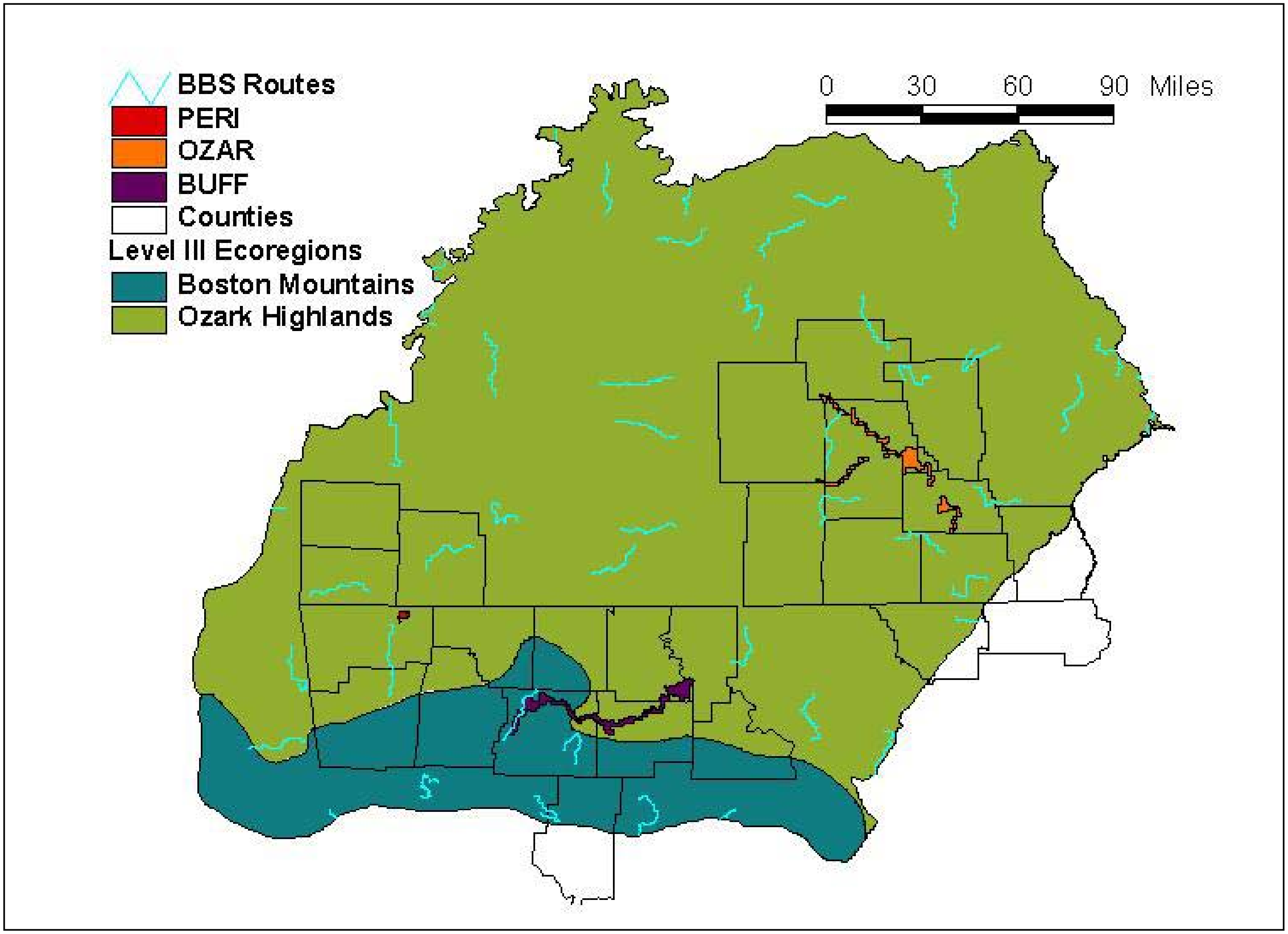


Figure 18. Locations of USGS real-time hydrologic gauges within watershed-defined study area of CUVA.