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Increasing development in the surroundings of U.S. National Park Service holdings jeopardizes park effectiveness

Urs Gimmi[a,b,*], Shelley L. Schmidt[a], Todd J. Hawbaker[a], Camilo Alcántara[a], Ulf Gafvert[c], Volker C. Radeloff[a]

[a] Department of Forest and Wildlife Ecology, University of Wisconsin, Madison, WI, USA
[b] Swiss Federal Research Institute WSL, Land Use Dynamics, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland
[c] Great Lakes Inventory and Monitoring Program, U.S. National Park Service, Ashland, WI, USA

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ABSTRACT

Protected areas are cornerstones of biodiversity conservation, but they are in danger of becoming islands in a sea of human dominated landscapes. Our question was if protected areas may even foster development in their surroundings because they provide amenities that attract development, thus causing the isolation of the ecosystems they were designed to protect. Our study analyzed historic aerial photographs and topographical maps to reconstruct road development and building growth within and around Indiana Dunes and Pictured Rocks National Lakeshores in the U.S. Great Lakes region from 1938 to 2005, and to estimate the effects of park creation in 1966 on changes in landscape patterns. Historic U.S. census housing density data were used as a baseline to compare observed changes to. Our results showed that park establishment was effective in reducing and stopping the fragmenting impact of development within park boundaries. However, increased amenity levels following park establishment led to enhanced development in the surroundings of both parks. In the extreme case of Indiana Dunes, building density outside the park increased from 45 to 200 buildings/km^2 and road density almost doubled from 3.6 to 6.6 km/km^2 from 1938 to 2005. Development rates of change were much higher than in the broader landscape, particularly after park establishment. The potential amenity effect was up to 9500 new buildings in the 3.2-km zone around Indiana Dunes between 1966 and 2005. For Pictured Rocks the absolute effect was smaller but up to 70% of the observed building growth was potentially due to amenity effects. Our findings highlight the need for conservation planning at broader scales, incorporating areas beyond the boundaries of protected areas.

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1. Introduction

Globally, landscapes and ecosystems are increasingly affected and transformed by human action (Turner, 1990; Vitousek et al., 1997; Goudie, 2006). In this context, protected areas have become cornerstones for biodiversity conservation (Noss, 1996; Bruner et al., 2001). However, protected areas are in danger of becoming islands in a sea of human dominated landscapes as land surrounding protected areas is increasingly converted to agriculture and urban land uses (Hansen et al., 2004; Radeloff et al., 2010). Land-use intensification in the surroundings of protected areas is of concern because it reduces additional adjacent habitat and causes ecological isolation (Struhsaker et al., 2005). Particularly for large predators park areas are often too small to support viable populations because park boundaries rarely coincide with ecological boundaries (Theberge et al., 2006; Patterson and Murray, 2008). Large predator populations are inextricably linked with the surrounding lands and consequently are faced with higher extirpation risk in case of increasing isolation (Newmark, 1995; Howe et al., 2007). Increasing conversion of habitats for human use may also limit management options inside protected areas (Hansen and DeFries, 2007). For example, densely built areas around protected areas make it more difficult to acquire additional land for park extensions (Turner et al., 2006).

Land-use change and housing growth surrounding protected areas has been fairly well quantified (e.g., DeFries et al., 2005; Radeloff et al., 2010). However, the effects of park establishment on rates of land-use change in and around protected areas are not well understood. Limited evidence suggests that protected areas may actually foster development in their surrounding areas. For example, population growth at the borders of 306 protected areas

* Corresponding author. Swiss Federal Research Institute WSL, Land Use Dynamics, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland.
E-mail address: urs.gimmi@wsl.ch (U. Gimmi).

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in Africa and Latin America is nearly double the average rural growth rate (Wittemyer et al., 2008). However, there are few longitudinal (long term) studies that have reconstructed land-use change before and after park establishment and systematically assessed the effects of park establishment on rates of change inside protected areas and in their surroundings (Ewers and Rodrigues, 2008). Long-term studies are important though to detect leakage effects – i.e., if actions that would have taken place inside a protected area (for example logging) are displaced to the surrounding area. And similarly, long-term studies are key to detect amenity effects – i.e., if the presence of a park creates economic and aesthetic conditions that attract additional development in the surrounding of protected areas.

What complicates matters further is that the effects of park establishment on development and land-use change are highly variable. In many cases, protected areas are fairly successful in stopping land-cover change and habitat loss within their boundaries (Bruner et al., 2001; Chape et al., 2005), but they are less successful in stopping habitat destruction outside their boundaries (DeFries et al., 2005). In the Peruvian Amazon for example, deforestation was effectively reduced within areas with land-use restriction but dramatically increased in the surrounding areas (Oliveira et al., 2007). In contrast, in the case of the Wolong Nature Reserve for Giant Pandas in China the rate of habitat loss inside the park area increased after park establishment, to rates similar or higher than those outside the reserve (Liu et al., 2001).

The main task of protected areas is biodiversity conservation and therefore, park effectiveness would ideally be assessed by comparing rates of biodiversity loss before and after the creation of a park. Direct measurements of biodiversity, however, are difficult to obtain. Instead, indicators are commonly used to measure potential biodiversity loss in a given area. The rate of deforestation is commonly used as a proxy for biodiversity loss in tropical regions of developing countries, where studies dealing with park effectiveness have been predominately conducted so far (DeFries et al., 2005; Gaveau et al., 2007; Linkie et al., 2008; Nagendra, 2008). However, protected areas in developed countries face different threats, and housing development in their surroundings may be a key indicator (Radeloff et al., 2010)

For the U.S., effects of increased amenity levels due to the establishment of preserved open space on housing growth have been found both in theory (Wu and Plantinga, 2003; Dearien et al., 2006; Walsh, 2007), and practice (Bockstael, 1996; Irwin and Bockstael, 2004). Conservation purchases influence land market dynamics and generate feedbacks that can undermine conservation goals (Armsworth et al., 2006). Proximity to protected areas has been related to higher development rates in general (McDonald et al., 2007) and increased population growth in particular (McGranahan, 1999, 2008). For example, the counties around Yellowstone National Park are among the fastest growing in the United States (Rasker and Hansen, 2000). Additionally, recreational and aesthetic amenities have been identified to be important factors for explaining changes in residential patterns over larger regions (Hammer et al., 2004).

Housing growth is usually accompanied by road development, and both roads and buildings have negative ecological impacts and are regarded as a major conservation threat. Habitat loss, increased mortality, altered hydrology, and landscape fragmentation are the most prominent ecological effects from the construction of roads and buildings (Forman and Alexander, 1998; Forman et al., 2003). Therefore, road and building density, and distance to roads and settlements are among the most important parameters when mapping the human footprint in a given area (Sanderson et al., 2002), and landscape fragmentation resulting from road and buildings serves as indicators for sustainable landscape development (Jaeger et al., 2008). Furthermore, roads and buildings are relatively easy to recognize from different data sources such as satellite and aerial imagery and topographical maps (Hawbaker and Radeloff, 2004) which enables straightforward reconstruction of changes in road and building density.

The main goal of our study was to assess the effects of park establishment on road and building development and concomitant landscape fragmentation. We conducted our study in and around Indiana Dunes and Pictured Rocks National Lakeshores. Based on aerial imagery and topographical maps, we reconstructed building and road densities for three time points (1938, 1966 and 2005) inside the park boundaries and within a 3.2-km zone adjacent to the parks and calculated rates of change for the period before and after park establishment (i.e., before and after 1966). We used rates of building growth, road development, and landscape fragmentation before park establishment as a temporal benchmark, and data from the broader landscape as a spatial baseline level. This approach enabled us to assess park effectiveness both in time (pre- and post-establishment period) and space (park area vs. adjacent zones vs. broader landscape), and estimated potential leakage and amenity effects due to park establishment.

2. Methods

2.1. Study area: Indiana Dunes and Pictured Rocks National Lakeshores

Our study was conducted in two National Park Service holdings in the U.S. Great Lakes region: Indiana Dunes National Lakeshore and Pictured Rocks National Lakeshore (Fig. 1). Both parks were established in 1966. Our analysis included the park area and a 3.2-km zone that is adjacent to the parks. We chose a radius of 3.2 km (2 miles) to capture the area where direct impacts of development on ecological processes in the protected area are likely, and where amenity effects are strongest. The 8.8 km^2 Indiana Dunes State Park adjacent to the National Lakeshore was excluded from the analysis because it could not be developed. The two parks represent two extremes of development within protected areas in the U.S. Great Lakes region from a highly urbanized (Indiana Dunes) to a sparsely populated region (Pictured Rocks). In the future, high levels of urban development pressure are expected for Indiana Dunes whereas for Pictured Rocks less development pressure is expected due to the more rural location.

Indiana Dunes National Lakeshore (Indiana Dunes in the following) is a category V park (protected landscape/seascape) according to the classification system of the World Conservation Union (IUCN). The park contains 24 km of Lake Michigan's shoreline and comprises over 50 km^2 of a once vast dune environment resulting from the retreat of the last glaciers. The biological diversity of Indiana Dunes is among the highest per unit area of all US national parks (Choi and Pavlovic, 1998). The Indiana Dunes are also interesting in the context of ecology's history as Henry Chandler Cowles developed his classic succession theory here after recognizing that vegetation on sand dunes of different ages represents different stages of a general trend of vegetation development (Cowles, 1899).

There is a long history of human impacts in and around Indiana Dunes. Native Americans traveled the dunes along major routes between the Great Lakes and the Mississippi River. After intense logging activities in the 1830s and 1840s (Williams, 1989) farmers moved into the region in the late 19th century. Industrial development started just west of the national lakeshore around 1900. Sand mining companies hauled large quantities of sand from the dunes for use in Chicago landfills and construction (Cockrell, 1988). Hoosier Slide for example, once the largest sand dune on Indiana's

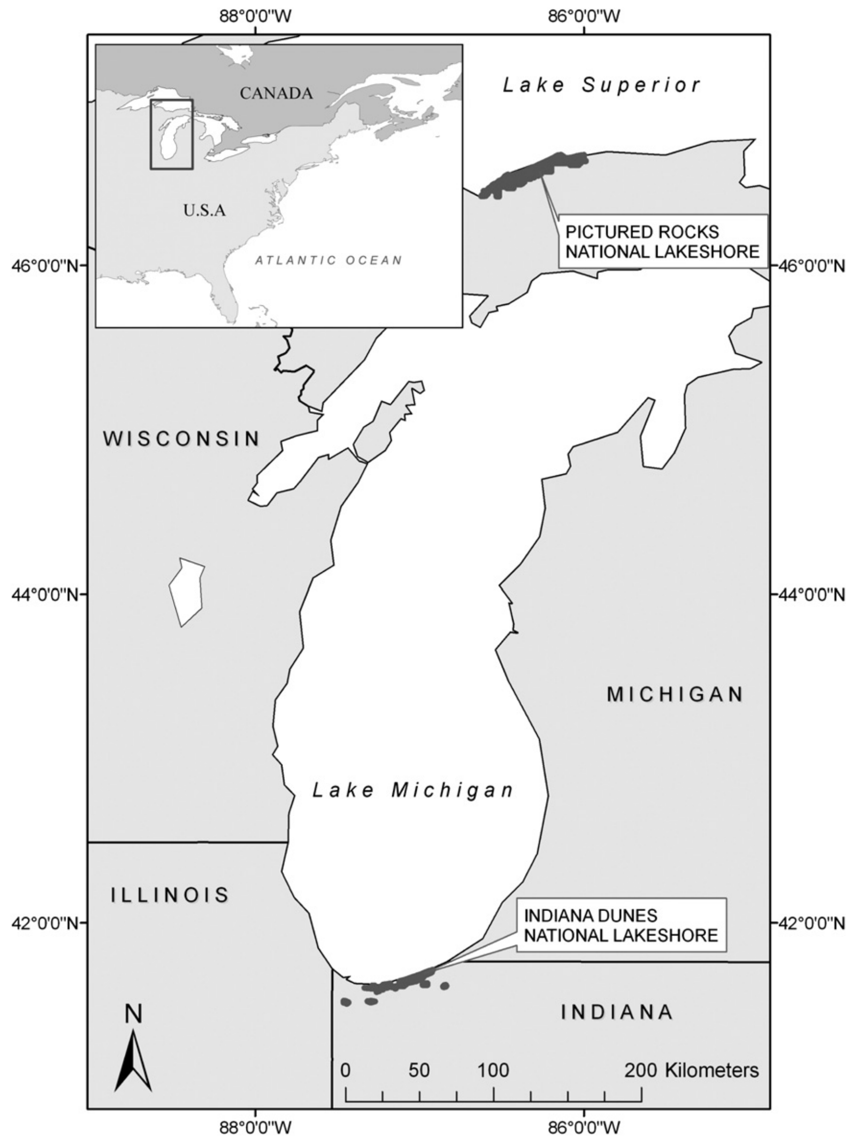

Fig. 1. Location of Indiana Dunes and Pictured Rocks National Lakeshores in the U.S. Great Lakes region. Indiana Dunes National Lakeshore consists of several spatially disjoint areas, including small holding to the South of the main unit.

lakeshore was carried away in railroad boxcars by manufacturers of glass fruit jars. By the 1930s, residential communities sprang up and the population escalated in the 1950s with the post-war economic boom. The late 1950s and early 1960s brought the development of a coal fired-power plant and a steel mill in the midst of extensive natural sand dunes and wetlands. In the same period, a nationwide campaign of conservationists blocked a plan to construct a "Port of Indiana" in the area where the park now exists. Today, Indiana Dunes is embedded within an urban matrix in the proximity of Chicago (Cockrell, 1988).

Pictured Rocks National Lakeshore (Pictured Rocks in the following) is designated as a category III park (natural monument) by the IUCN. Pictured Rocks is located in the North of Michigan's Upper Peninsula and contains 67 km of Lake Superior's shoreline and almost 275 km^2 of post-glacial landscape. The region is sparsely populated and densely wooded within the transition zone between boreal and northern hardwood forests. Similar to Indiana Dunes, human disturbances in the region have a long history. The discovery of iron on Michigan's Upper Peninsula in the mid-19th century led to the construction of a vast mining and manufacturing industry (http://www.nps.gov/piro/historyculture). When the American Civil War ended in 1865, many of the South's furnaces had been destroyed, but with the westward expansion, the demand for iron boomed. During this era many of the Upper Peninsula's furnaces were constructed, and local timber was used as charcoal. In the last decades of the 19th century Michigan's Upper Peninsula was discovered by the developing recreation and logging industries. The seemingly unlimited forests of the region attracted lumbermen who had exhausted their timber resources in the East (Williams, 1989). Similarly, the scenic landscape lured people living in overcrowded expanding urban centers (Vogel, 2000). Timber industry and tourism initiated railway construction and the number of recreationists additionally grew as the automobile became increasingly popular after the 1920s.

2.2. Historic building and road data

2.2.1. Local-scale analyses

We digitized roads and buildings for three time points (1938, 1966 and 2005) combining aerial photographs and topographical maps. Information for the initial (1938) and current (2005) condition was derived from aerial photographs. We scanned and orthorectified 1:20,000 black and white diapositives (1938) and 1:12,000 natural color orthophotos (2005). For the 1966 time point we used scanned and georeferenced 1:24,000 scale U.S. Geological Survey topographical maps (published between 1962 and 1968). All visible buildings were digitized as points and roads as lines. On the topographical maps, densely built areas are shown as contiguous areas without indicating single buildings. We digitized these areas as polygons of urban areas and assigned 700 buildings/km^2 building density to these areas based on the average building density for urban areas depicted on the topographical maps and measured for a sample of aerial photographs available for the mid-1960s. Cross-referencing both data types was possible for some parts of the study area where aerial photographs for the mid-1960s and both recent and early 1940s topographical maps were available. No significant bias was found between data types (>95% consistency for building density and 98% for road density); consistent with similar findings for Northern Wisconsin (Hawbaker and Radeloff, 2004).

From the digitized data we calculated road density (km/km^2) and building density (buildings/km^2) for each time step separately for the park areas and the adjacent zones considering only the land portion of the areas. Road development and building growth were calculated for the pre- and post-establishment period (before and after 1966).

Finally, we analyzed the effects of roads and buildings on landscape fragmentation. For this purpose, we first applied a 50 m zone of influence around each building and urban area and a 25 m zone of influence around each road to define a conservative estimate of direct human disturbance (Gonzalez-Abraham et al., 2007). Disturbed areas derived from roads, buildings, and urban areas were then aggregated to a total disturbance matrix and remaining unaffected patches (Fig. 2). At Pictured Rocks unaffected patches consist almost exclusively of forests, wetlands and sand dunes whereas in the 3.2-km zone around Indiana Dunes substantial areas are under agricultural use. Based on this binary land-cover map we applied morphological image processing (Vogt et al., 2007a). Morphological image processing assesses the spatial configuration of an entire landscape, in contrast to landscape indices which describe the structural elements of a landscape. The approach is frequently used to analyze edge and connectivity aspects in fragmented forest landscapes (Vogt et al., 2007b; Ostapowicz et al., 2008). Morphological spatial pattern analysis allocates each foreground pixel (in our case the pixels unaffected by roads and houses) to one of the mutually exclusive thematic pattern classes. We used a limited number of classes and allocated each 50-m resolution pixel as either 'edge', 'core', or 'patch'. For our study, 'edge' is defined as an undisturbed 50 m pixel adjacent to the disturbed matrix, 'core' indicates undisturbed pixels that are separated by 'edge' from the disturbed area, and 'patch' comprises undisturbed regions that are too small to contain 'core'. Landscape patterns were analyzed by calculating landscape indices such as the total area of each land-cover class, and mean, median, and maximum size of contiguous core areas both for the park area, the 3.2-km zone, and the total area and for all three time points.

2.2.2. Broad-scale analysis

We used U.S. Census housing density data from 1940 to 2000 at the partial block group level (the finest spatial resolution at which US Census data provide historic housing density estimates, Hammer et al., 2004; Radeloff et al., 2005) to compare observed development rates surrounding the protected area with those in the broader landscape. For this purpose we defined reference areas (Fig. 3) both at the county scale (Lake, Porter and La Porte counties for Indiana Dunes; Alger and Schoolcraft counties for Pictured Rocks) and at the regional scale. To ensure the comparability between the 3.2-km zone and the regional scale reference areas (Mas, 2005) we first assessed their similarity in respect of their general amenity levels. Similar amenity level was defined as a similar distance to the Great

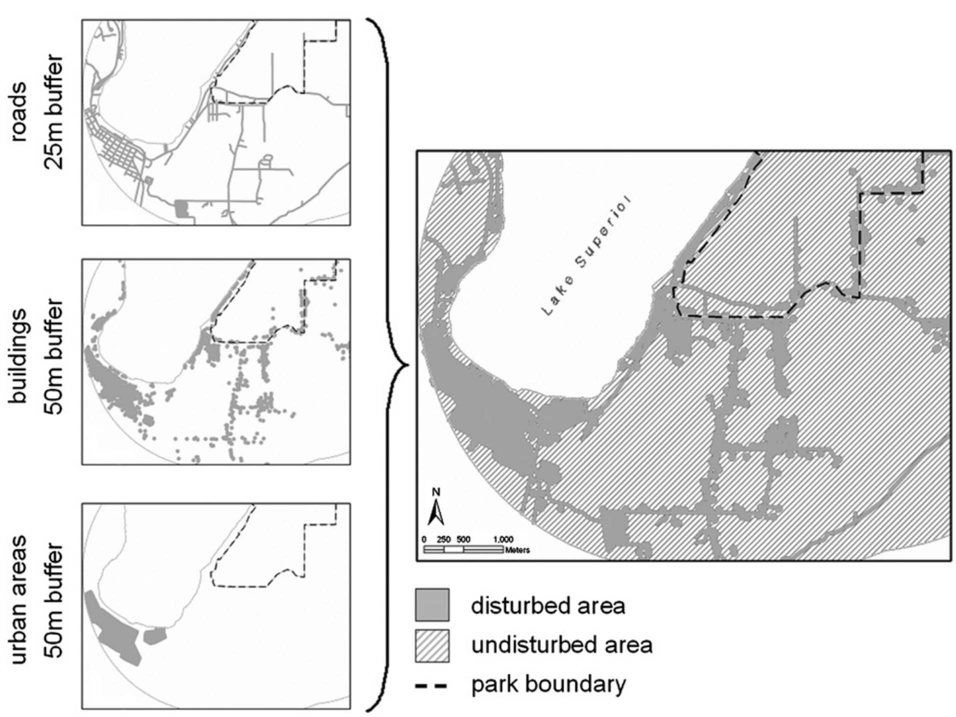

Fig. 2. Aggregation of areas disturbed by roads, buildings, and urban areas to total disturbed area and remaining areas unaffected by roads and buildings. Examples from the Pictured Rocks National Lakeshore. The dashed line shows the park boundary.

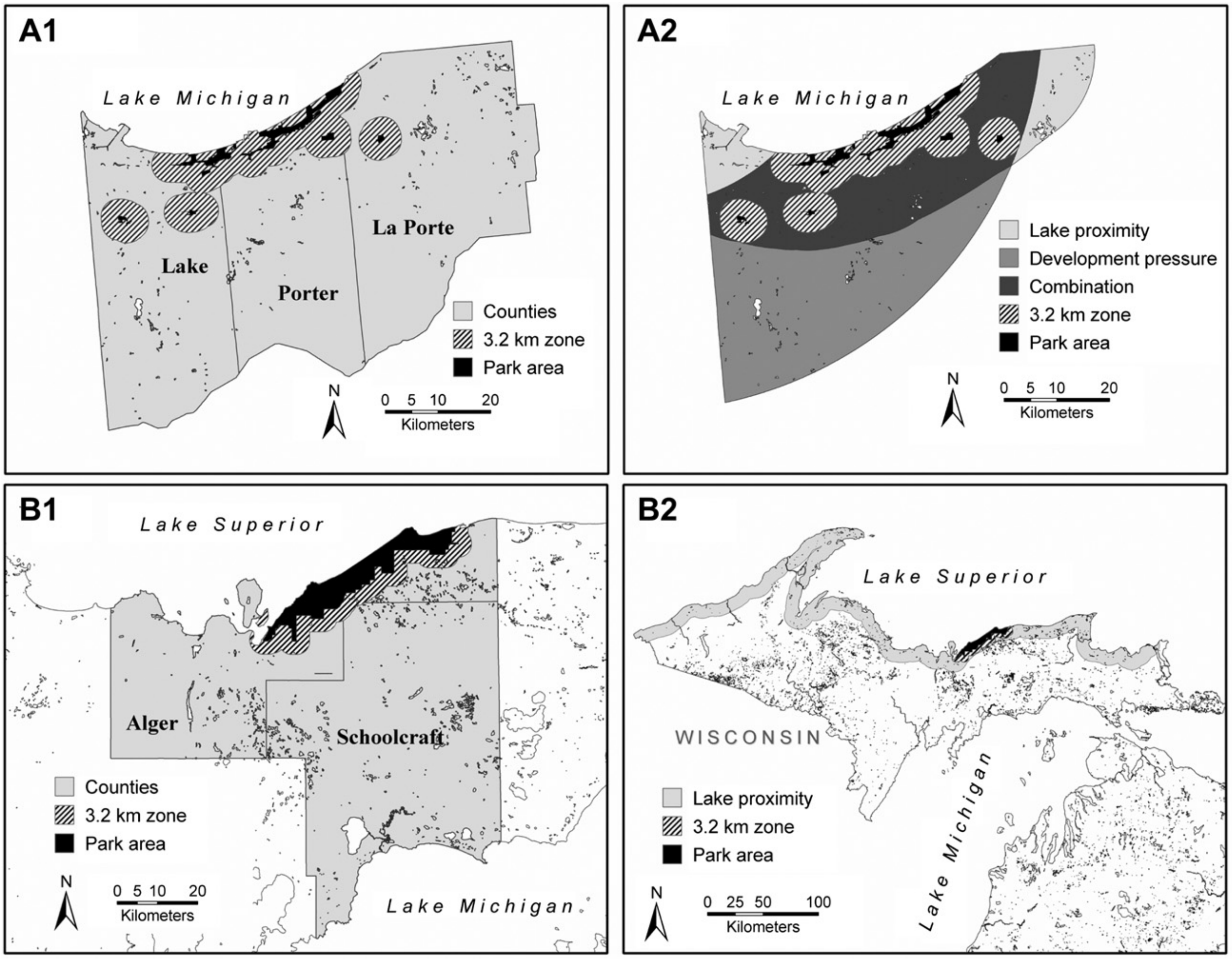

Fig. 3. Study design for Indiana Dunes (A) and Pictured Rocks (B). Local-scale analysis includes the park areas and the 3.2-km adjacent zone with digitized data from aerial photographs and topographical maps. The broad-scale analysis for the reference areas was conducted with historic US census housing density data both at county scale (A1 and B1) and regional scale (A2 and B2).

Lakes (i.e., to Lake Michigan for Indiana Dunes and to Lake Superior for Pictured Rocks). Within the 3.2-km zone of the two respective parts, the maximum distance to the lake was 11.2 km for Pictured Rocks and to 18 km for Indiana Dunes. We applied these distances to define a region with similar amenity level along Indiana's Lake Michigan's shoreline and Michigan's Lake Superior Shoreline. For Indiana Dunes we additionally defined a reference region of similar development pressure due to the proximity to the Chicago metropolitan area. Here we evaluated the minimum and maximum distance to Chicago downtown for the 3.2-km zone (37.1 km and 76.1 km respectively) and created a ring within the State of Indiana applying this distance range.

For the comparison of development patterns at the beginning of the study period we stratified 1940 partial block group housing data into four categories ranging from sparsely to densely developed to for both the reference areas and the 3.2-km zone and calculated their relative proportion (Table 1). We used area weighting to allocate housing densities for partial block groups that were only partially contained within a specific area. The proportions between the categories were quite similar for Pictured Rocks (more than 95% of the area with housing density below 10 housing units per km^2), suggesting similar housing patterns at the start of the study period in the 3.2-km zone and the reference areas. For Indiana Dunes, in contrast, the fraction of moderately dense and densely built areas was clearly higher in the 3.2-km zone than in all reference areas. Apparently, the landscape of reference areas was dominated by a more rural housing pattern, while the 3.2-km zone around Indiana Dunes contained a larger proportion of urban area

Table 1
Percentage of area for different categories of housing densities for the 3.2-km zone around the parks and the reference areas (county and regional levels) based on values from the U.S historic housing census data from 1940.

	Indiana Dunes			Pictured Rocks		
	3.2-km zone	County level	Regional level	3.2-km zone	County level	Regional level
Sparsely built (<1 housing unit/km^2)	20.4	18.4	12–16.5	85.1	76.1	64.7
Moderately low (1–10 hu/km^2)	33.3	67.6	52.7–65.5	12.6	23.5	33.5
Moderately dense (10–100 hu/km^2)	26.9	9.3	16.5–24.7	1.8	0.4	1.4
Densely built (>100 hu/km^2)	19.4	4.7	6–12.2	0.4	0.1	0.3

at the start of the study period. To balance these dissimilarities we used the values calculated for the 3.2-km zone as weighting factors for the reference areas, i.e., we created reference areas that are comparable to the 3.2-km zones in terms of their housing patterns at the start of the study period. From the partial block group data we calculated building densities for 1938 applying the weights calculated above for all reference areas. Densities for 1966 and 2005 were calculated based on the weighted reference areas. Finally, we calculated absolute and relative building growth for the pre- and post-establishment period and compared all these values with the observed development in the park area and the 3.2-km zone respectively.

2.2.3. Assessment of leakage and amenity effects

Based on the results of the local- and broad-scale analysis we developed coarse counterfactual scenarios to estimate potential leakage and amenity effects of park establishment on surrounding building growth, i.e., we ask the question how road development and building growth would have developed if the parks would not have been established in 1966. Both scenarios were based on the assumption that broad-scale relative building growth rates after 1966 (both at county scale and regional scale) captured the regional development pressure for the post-establishment period. We defined the potential leakage effect ($leak_{pot}$) as the difference between the estimated building growth within the park area (bg_park_{exp}) – applying post-establishment growth rates from the broad-scale reference areas to the park area – and the observed building growth (bg_park_{obs})

$$leak_{pot} = bg\_park_{exp} - bg\_park_{obs} \quad (1)$$

The potential leakage effect can also be interpreted as the maximum number of buildings prevented by park establishment.

The potential amenity effect ($amen_{pot}$) was defined as the difference between the observed post-establishment building growth in the 3.2 km adjacent zone (bg_adj_{obs}) and the expected building growth in the same area (bg_adj_{exp}) using again the building growth values from the broad-scale reference areas between 1966 and 2005.

$$amen_{pot} = bg\_adj_{obs} - bg\_adj_{exp} \quad (2)$$

3. Results

3.1. Building growth

In terms of limiting new buildings within the parks, both parks were effective. Building density within the boundaries of both parks was clearly lower than in the 3.2-km zones around the parks and in the reference areas for all time points and building growth within the protected areas remained at very low levels for both the pre- and post-establishment period (Fig. 4). Inside Pictured Rocks National Lakeshore, building density even slightly decreased after park establishment due to active removal of a number of vacation homes.

In the 3.2-km zone around Indiana Dunes, building density increased at very high rates already before park establishment and although absolute and relative growth slightly slowed down after 1966, building growth was still clearly above the values of the reference areas. 2005 building density in the 3.2-km zone adjacent to Indiana Dunes was equivalent to 200 buildings/km^2, which is an almost 350% increase since 1938 (45 buildings/km^2). At Pictured Rocks, building growth in the 3.2-km zone was very low in the pre-establishment period probably as a consequence of agricultural abandonment in this region. Thus, building density increased only by 2.3% between 1938 and 1966. In contrast, in the same area building density increased by 62% after park establishment, a relatively high rate of growth compared to the rates in reference areas (37% at county scale and 46% at regional scale).

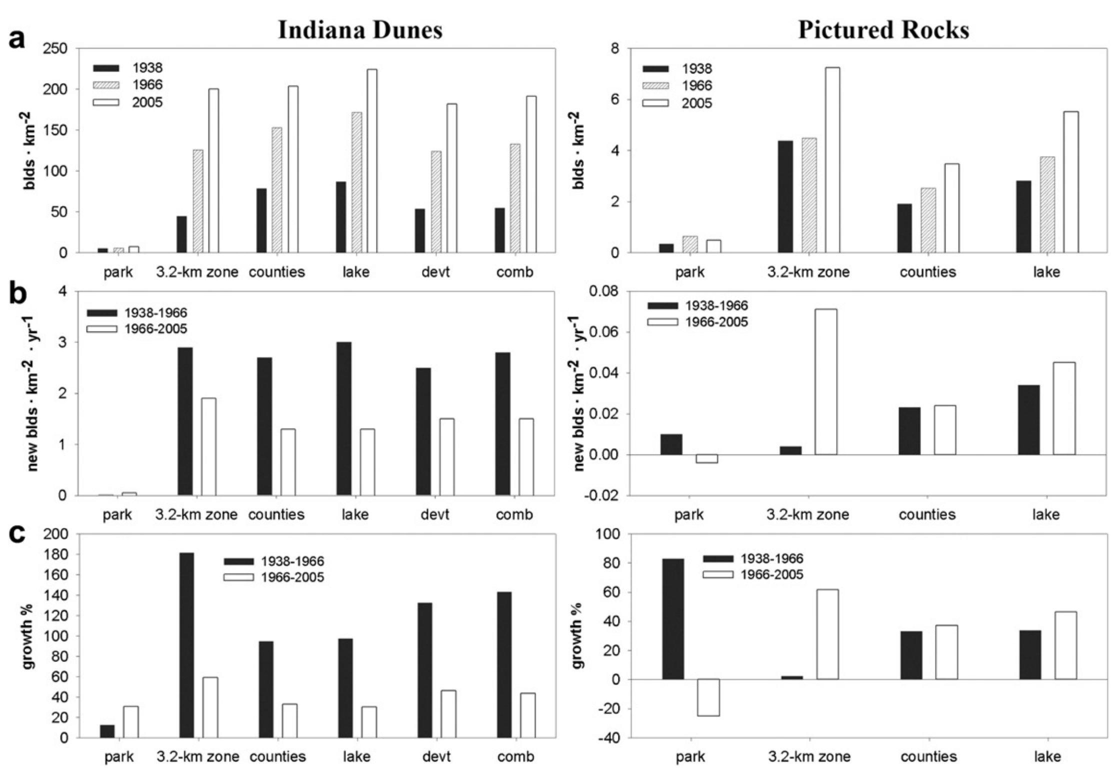

Fig. 4. Changes in building density (a) between 1938 and 2005, absolute (b) and relative (c) building growth for pre- and post-establishment period within Indiana Dunes and Pictured Rocks National Lakeshores, the 3.2-km zones adjacent to the parks, and reference areas at county and regional scales.

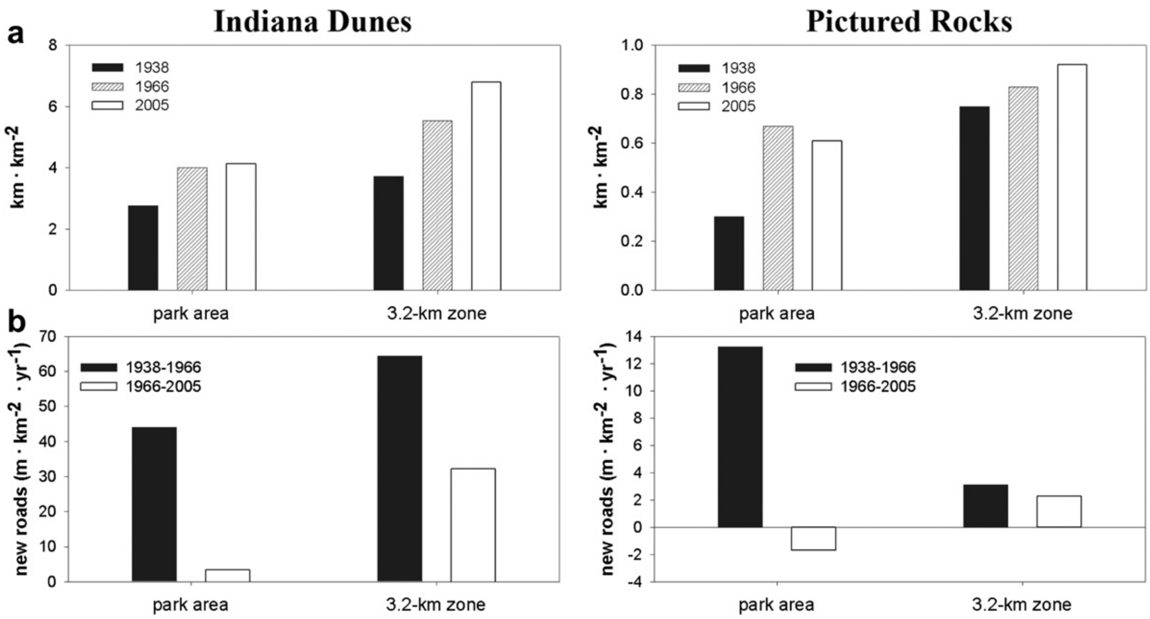

Fig. 5. Changes in road density between 1938 and 2005 (a) and road development for pre- and post-establishment period (b) within Indiana Dunes and Pictured Rocks National Lakeshores and the 3.2-km zones adjacent to the parks.

3.2. Road development

Road density inside both parks was lower than in the 3.2-km zones adjacent to the parks for all three time points (Fig. 5). However, the differences were much less pronounced for roads than for building density. Before 1966 road development within Indiana Dunes was on a similar level as within the 3.2-km zone (44 vs. 65 m new roads/km^2 per year). After park establishment, road development was essentially stopped within Indiana Dunes park area, whereas 32 m new roads/km^2 per year were built in the 3.2-km zone around the park.

At Pictured Rocks, the highest rates of road development were found within the park in the pre-establishment period (13.2 m new roads/km^2 per year). Here, road density more than doubled from 0.3 km/km^2 to 0.67 km/km^2. After park establishment, some of this development was reversed and a total of 17.4 km of roads were closed. In the 3.2-km zone around the park, road density continuously grew from 0.75 km/km^2 in 1938 to 0.92 km/km^2 in 2005 with rates around 3 m new roads per km^2 and year.

3.3. Changes in landscape patterns

Road development and building growth fragmented landscapes in and around the two parks (Fig. 6). Expansion of the disturbed area from 1938 to 2005 within the Indiana Dunes area was vast. Almost 50% of the total landscape in 2005 was affected when assuming 25- and 50-m disturbance zones around roads and building respectively (Table 2). The expansion of the disturbed area was largely restricted to the 3.2-km zone adjacent to the park. Within the park, the increase in the proportion of disturbed area was minor until 1966 and almost zero after park establishment. Inside Indiana Dunes, the proportion of core area shrank only slightly from 64.5% in 1938 to 61.3% in 2005 and almost no loss of core area occurred after park establishment. Proportion of edge and patch area remained stable over time. In contrast, in the 3.2-km zone around the park the amount of core area decreased dramatically. In 2005, less than 30% of the landscape around the park remained as core. Interestingly, the proportion of edge area decreased much less than the proportion of core areas over the whole period, which indicates that the area undisturbed by roads and buildings not only shrank but also geometrically became more complex over time. Furthermore, inside Indiana Dunes, mean and median size of the core areas increased before and after park establishment (Table 3). In the 3.2-km zone the number of cores slightly increased, but mean, median, and maximum size of the core areas decreased. However, the largest core area of the entire landscape expanded after 1966.

In comparison to Indiana Dunes, the proportion of disturbed area was generally much lower in Pictured Rocks (Table 2). In 2005, only 3.2% of the park area and 5.8% of the 3.2-km zone was affected by roads and buildings. The impact of building growth and road development on changes in landscape patterns in Pictured Rocks was mostly restricted to the pre-establishment period. Within the park, the proportion of core area dropped from almost 95% in 1938 to 88.6% in 1966 but increased again to almost 90% in 2005. Additionally, mean, median and largest core all increased after park establishment inside the park (Table 3). For the entire area the loss of core area was stopped after park establishment. The largest core also increased in size even in the 3.2-km zone and almost doubled in the entire area. The proportion of edge area was greater than the amount of disturbed area for all time steps and for both within and outside the park. The amount of patch area in Pictured Rocks was negligible for the park and the adjacent zone and for all time steps.

3.4. Leakage and amenity effects

Our estimation of leakage effects suggested that the creation of Indiana Dunes National Lakeshore potentially prevented up to 2900 new buildings (or 55 buildings/km^2 additional building growth) within the park area in the period between 1966 and 2005 (Table 4). However, during this time almost 31,000 new buildings were constructed in the 3.2-km zone adjacent to the park, and this represented 6800–9500 buildings (16–23 buildings/km^2) more than would be expected based on relative building growth rates in the broader landscape. These numbers represent 22–31% of the observed building growth in the post-establishment period. In

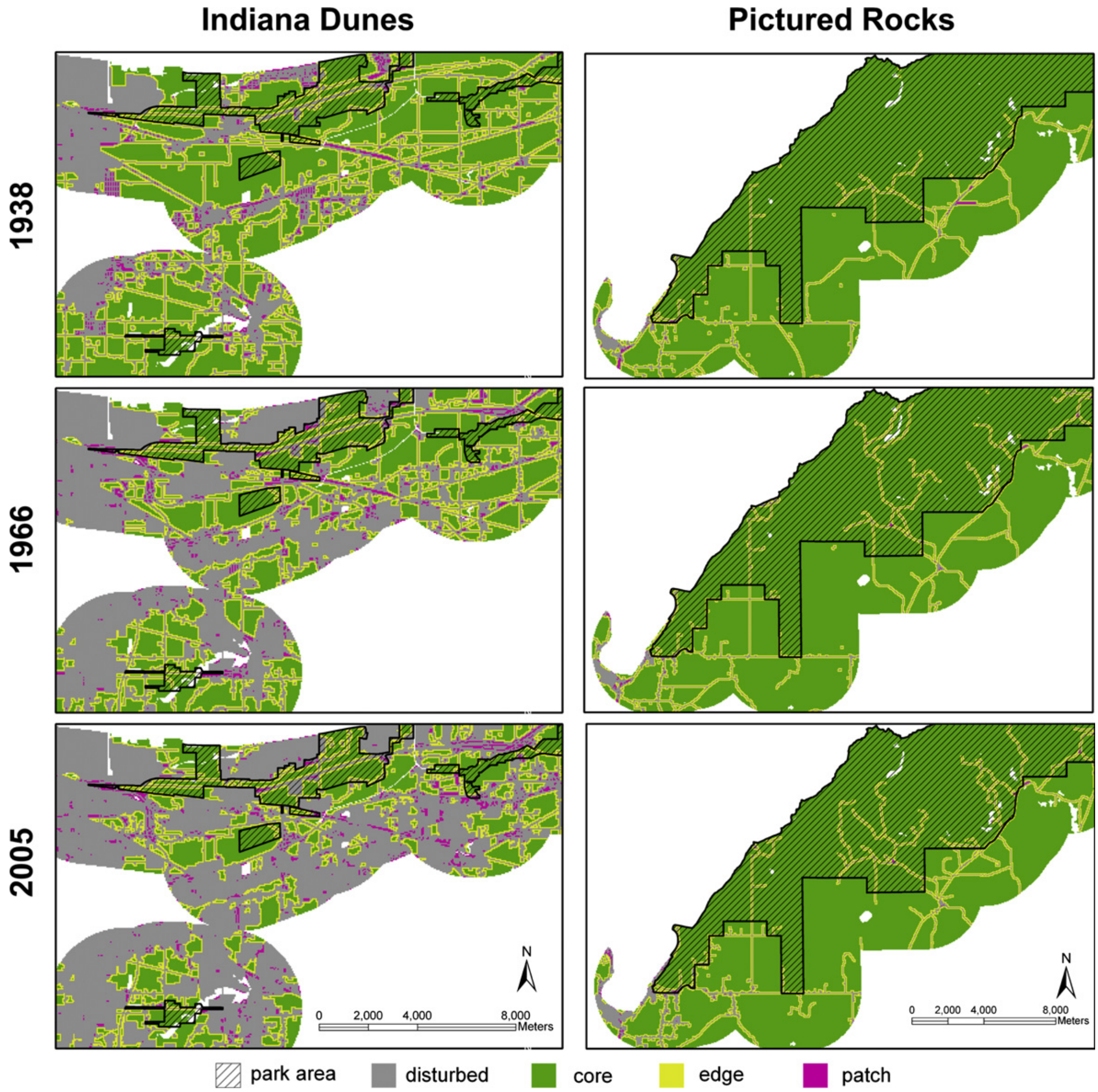

Fig. 6. Landscape fragmentation due to roads and buildings for selected parts of Indiana Dunes and Pictured Rocks National Lakeshores for 1938, 1966 and 2005.

other words, our results show that there may have been a moderate leakage effect, and that there was almost certainly a strong amenity effect due to park establishment.

For Pictured Rocks the potential leakage effect amounted to 290–510 buildings. This was almost exactly equal to the potential amenity effect (Table 4). Because the two effects were similar, we were not able to ascertain which effect dominated. However, 40–70% of the observed building growth after park establishment in the 3.2-km zone potentially stemmed from either leakage or amenity effects.

Table 2
Percentage of area disturbed by roads and buildings and percentage of unaffected core, edge, and patch area for Indiana Dunes and Pictured Rocks National Lakeshores inside the park area, the 3.2-km zone, and the total area between 1938 and 2005.

		Indiana Dunes				Pictured Rocks			
		Disturbed area	Core area	Edge area	Patch area	Disturbed area	Core area	Edge area	Patch area
Park area	1938	14.7	64.5	19.0	1.8	1.7	94.8	3.5	0.1
	1966	16.2	62.2	19.1	2.5	3.6	88.6	7.6	0.2
	2005	17.5	61.3	19.4	1.9	3.2	89.9	6.8	0.1
3.2-km zone	1938	23.8	55.7	18.7	1.8	4.3	88.0	7.5	0.2
	1966	38.2	42.0	17.7	2.2	4.8	87.0	8.1	0.2
	2005	52.4	28.6	16.3	2.7	5.8	85.6	8.4	0.2
Total area	1938	22.8	56.3	19.2	1.8	2.9	91.4	5.5	0.1
	1966	35.7	43.8	18.3	2.2	4.2	87.7	8.0	0.2
	2005	48.6	31.7	17.1	2.6	4.5	87.7	7.9	0.2

Table 3
Changes in the number of core areas and mean, median size, and maximum size of cores for Indiana Dunes and Pictured Rocks National Lakeshores inside the park area, the 3.2-km zone, and the total area between 1938 and 2005.

		Indiana Dunes				Pictured Rocks			
		Number of core areas	Mean core size (km^2)	Median core size (km^2)	Largest core (km^2)	Number of core areas	Mean core size (km^2)	Median core size (km^2)	Largest core (km^2)
Park area	1938	111	.30	.04	3.38	25	10.11	.03	176.61
	1966	106	.31	.05	3.24	61	3.90	.02	83.08
	2005	100	.32	.06	2.86	46	5.21	.15	143.69
3.2-km zone	1938	653	.36	.05	10.30	97	2.26	.06	26.36
	1966	660	.27	.04	6.89	105	2.06	.11	25.97
	2005	671	.18	.02	6.42	103	2.07	.05	30.25
Total area	1938	641	.42	.06	13.98	98	4.81	.02	242.28
	1966	638	.33	.06	6.74	149	3.03	.02	94.43
	2005	675	.22	.03	7.26	118	3.83	.02	186.82

4. Discussion

Both Indiana Dunes and Pictured Rocks National Lakeshores successfully reduced or stopped fragmenting impacts of road development and building growth after park establishment within their boundaries. In some cases, active management efforts, such as road closure, removal of buildings and connectivity projects could even reverse effects on landscape patterns of past development inside park areas. This was particularly true for Pictured Rocks, where a number of vacation homes were removed near the shoreline and their access roads were closed soon after creation of the park (pers. communication NPS staff).

In contrast to the conservation success story inside the parks though, areas surrounding both parks exhibited enhanced development and landscape fragmentation following park establishment. Building growth in the 3.2-km zones of both parks was more pronounced than we would expect from the trends calculated for the broader landscape. This can – especially for Indiana Dunes – only partially be explained by potential leakage effects (i.e., the displacement of development that would have occurred in the park area had the park not been established). Our results suggest that increased surrounding development is likely due to an amenity effect of the protected areas themselves, i.e., a result of enhanced recreational and aesthetic amenities that made the immediate surroundings of the protected areas particularly attractive for housing (McGranahan, 1999; Hammer et al., 2004). Additionally, economic amenities such as job opportunities directly or indirectly related to the park may play a role particularly for Pictured Rocks because the Michigan's Upper Peninsula is an economically underdeveloped region. We found amenity effects for both study areas although general development pressure was much higher in Northern Indiana than in Michigan's Upper Peninsula.

The results of past development are quite different between parks, although the general trends were the same. In the extreme case of Indiana Dunes, the park has become an island within a sea of development, and there is even a "moat" of high building density in the immediate surroundings of Indiana Dunes. However, lower absolute and relative rates of road development and housing growth after 1966 compared to pre-establishment values suggest that development may have reached its maximum in the zone adjacent to Indiana Dunes. In comparison, Pictured Rocks is in a still relatively undeveloped region. However, regions with initially low building and road densities may be even more susceptible to additional development (Hansen et al., 2005). Relative building growth after park establishment in the 3.2-km zone around the park was found to be high which is typical for rural residential development (Hansen et al., 2005; Radeloff et al., 2005) and population trends (Brown et al., 2005) during recent decades. The results have to be seen in the context of a general migration trend in the last few decades to non-urban regions with especially high levels of natural amenity such as mountain areas (Moss, 2006) or parts of the U.S. Great Lakes region (Nelson, 2006). Vicinity to public lands represents an additionally important recreational amenity particularly for the U.S. as public lands are accessible in contrast to most private lands. It is therefore not surprising that housing growth is often concentrated along public land boundaries (Hammer et al., 2009; Radeloff et al., 2010).

Our results strongly suggest that the protected areas fostered development in their surrounding areas. However, we urge readers to interpret our results with caution because of potential endogeneity problems. Endogeneity problems occur because protected areas are not simply randomly distributed over the landscape. For example, protected areas are disproportionately located on less productive landscapes (Hansen and Rotella, 2001). The creation of a protected area at a specific location at a specific point in time is a result of the interaction between biophysical factors, landownership, land-use history, socioeconomic circumstances, and last but not least political considerations. The establishment of Indiana Dunes, for example, was a last minute action after a nationwide campaign of conservationists to preserve the last remnants of a once vast dune landscape along the southern Lake Michigan's shoreline (Cockrell, 1988). In other words, high development rates were partly the reason for the establishment of the park. Endogeneity can confound attempts to quantify effects of park establishment when simply comparing changes inside protected areas with those in their surrounding. In addition to the inside/outside

Table 4
Potential leakage and amenity effects after park establishment (1966–2005) for Indiana Dunes and Picture Rocks. The potential leakage effect is calculated by the expected (using county and regional scale growth rates) building growth minus the observed building growth within the park area. The potential amenity effect is defined as the observed minus the expected building growth in the 3.2-km zone adjacent to the park.

	Indiana Dunes		Pictured Rocks	
	Potential leakage effect	Potential amenity effect	Potential leakage effect	Potential amenity effect
Number of buildings	2500–2900	6800–9500	290–510	250–450
Number of buildings per km^2	6.2–7.1	16.3–23.9	1.2–2.1	1.0–1.8

comparison we included a temporal dimension in the data by comparing rates of change before and after park establishment in our study. This enables a more pure measure of the park effect. In the pre-establishment period road development and building growth were on a similar level in the park area and the 3.2-km zone with the exception of building growth inside Indiana Dunes National Lakeshore which was essentially lower than in the adjacent zone. We can assume to a certain degree that after 1966 development inside park boundaries would have reached similar rates than in the 3.2-km zone without park establishment.

In our two case studies building growth and road development were useful for measuring park effectiveness and detecting effects of park establishment on surrounding areas, and they may provide better indicators for park effectiveness than forest cover change in developed countries where large scale deforestation is highly unlikely. Housing and road data can be collected with relative ease for other protected areas since the necessary information (aerial photos and/or topographical maps) are commonly available. Therefore, we propose road development and building growth in and around protected areas as a meaningful tool for studying past human impact and monitor current and future development in and around protected areas for developed countries.

5. Conclusions

The two case studies from Indiana Dunes and Pictured Rocks National Lakeshores empirically document accelerated growth rates in surrounding areas after park establishment. Such effects have to be taken into account in the context of decisions concerning the establishment of new protected areas, park extensions, and changes of the park status (e.g. implementation of wilderness areas). Our findings highlight the need for conservation planning looking at the broader landscape beyond the boundaries of protected areas (DeFries et al., 2007). The results also raise questions concerning the ecological functioning of the landscape as a whole as increased development in the surrounding of protected areas can cause considerable negative edge effects, such as reduced habitat connectivity and increased human-related mortality (Revilla et al., 2001). This challenges park managers to include considerations about landscape connectivity and corridors between habitats inside and outside the parks (Ament et al., 2008). Park management in this context requires further efforts to limit fragmentation within park landscapes and proactive management strategies to address the problem of growing development in the surrounding of protected areas. Park managers worldwide are increasingly aware of the negative effects of increasing development in the park surroundings and the problem has been included in the IUCN's systems for assessing protected areas management effectiveness (Hockings et al., 2000; Hockings, 2003). Our results highlight the need for National Park management in the U.S. and other developed countries to address ecological effects of increasing development in the surroundings of protected areas. Even though direct influence capability on private land development – especially in the U.S. – is limited, there is a number of encouraging examples which demonstrate how landscape planning can be effective in guiding development around parks (see Howe et al., 1997). Clustered development and minimum lot size are the most prominent conservation zoning measures although with quite different underlying objectives. Clustering development may be effective in maintaining important corridors and preventing development near ecologically sensitive areas. Defining a minimum lot size is useful to limit the absolute number of buildings in the landscape (e.g. one unit per 42 acres (ca. 17 ha) for private inholdings within Adirondack Park). Nongovernmental institutions such as land trust and conservation easements can offer tax incentives to landowners in exchange for limiting future development (Merenlender et al., 2004; Rissman et al., 2007). Participatory approaches however are crucial for the acceptance and the effectiveness of such planning at regional scale (Howe et al., 1997). Finally, individual homeowners can limit the ecological impact of their homes with simple measures such as limiting noise and light pollution, landscaping with native plants and keeping pets inside or leashed.

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