LANDSCAPE PATTERN INDICATORS FOR THE NATION

A REPORT FROM THE HEINZ CENTER'S LANDSCAPE PATTERN TASK GROUP

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State of the Nation's Ecosystems Project

THE H. JOHN HEINZ III CENTER FOR
SCIENCE, ECONOMICS AND THE ENVIRONMENT

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Landscape Pattern Task Group

Norman Christensen (Chair)
Professor of Ecology & Founding Dean
Nicholas School of the Environment and Earth Sciences
Duke University

G. Thomas Bancroft
Vice President and Chief Scientist
National Audubon Society

Susan S. Bell
Professor
Department of Biology
University of South Florida

Rick Brown
Senior Resource Specialist
Defenders of Wildlife

Chris Frissell
Senior Staff Scientist
Pacific Rivers Council

Sharon Haines (*Deceased*)
Director, Sustainable Forestry & Forest Policy
International Paper

Dan Heagerty
Senior Vice President and Director of Natural Resources
David Evans and Associates

K. Bruce Jones
Senior Scientist, Office of Research and Development
National Exposure Research Laboratory
U.S. Environmental Protection Agency

A.J. Jordan
Area Representative
Halderman Farm Management Service, Inc.

John Kupfer
Associate Professor
Department of Geography
University of South Carolina

James A. LaGro, Jr.
Professor & Chair
Department of Urban & Regional Planning
University of Wisconsin-Madison

Kurt Riitters
Research Scientist
Southern Research Station
USDA Forest Service

Gary J. Roloff
Assistant Professor
Department of Fisheries and Wildlife
Michigan State University
formerly with Boise Cascade Corporation

Ed Thompson, Jr.
Senior Vice President for Public Policy
American Farmland Trust

Agency Liaison
John E. Gross
Ecologist
Inventory and Monitoring Program
National Park Service

Heinz Center Project Staff
Robin O'Malley
Program Director

Kent Cavender-Bares
Senior Research Associate

Caroline Cremer
Research Assistant

Former Heinz Center Project Staff
Holly Alyssa MacCormick
Research Assistant

The H. John Heinz III Center for Science, Economics and the Environment
900 17th Street, NW, Suite 700 | Washington, D.C. 20006
Phone: (202) 737-6307 • Fax: (202) 737-6410 • www.heinzcenter.org

EXECUTIVE SUMMARY

***Note to the Reader*—**This report was drafted and subjected to a thorough external review with the expectation that it would be released prior to the completion of the *2008 State of the Nation's Ecosystems* report. However, for a variety of reasons, the final version of this report was completed only after the June 2008 release of the *2008 State of the Nation's Ecosystems* report. We have attempted to revise the wording throughout to reflect the realities of the timelines from these two reports, although there remain instances that could lead to some confusion. It is essential to realize that *all* of the recommendations made by the Landscape Pattern Task Group that are detailed in this report were incorporated into the *2008 State of the Nation's Ecosystems Report*.

What Is in this Report?

This report contains recommendations for a suite of indicators designed to describe broad patterns of landscapes on a national scale. Landscape patterns include naturally-occurring phenomena, such as the intermingling of shrublands and forests, as well as clearly human-created patterns such as the spread of development into previously undeveloped areas. In general, the indicators in this report illuminate the human-mediated changes to landscapes rather than the heterogeneity that is a natural feature of landscapes.

These indicators are meant to evaluate the *structure* of landscapes through a lens that hopefully captures some aspects of ecosystem *function*. Why not simply report those aspects of landscape pattern that capture all of the important elements of ecosystem function? Quite simply, the numerous species involved and their varied responses to changes in landscape structure present a daunting challenge for ecologists to understand, let alone generalize. Further, landscape pattern is just one element of ecosystem structure, and structure is just one element of ecosystem function. Hence, the indicators recommended, while based on the latest scientific literature, have been developed with the realistic view that any one of them would not be able to “be all things to all people.”

This report includes eight indicators of landscape pattern. One of these is an overarching, cross-ecosystem indicator, while the others describe patterns in a manner tailored to particular ecosystem types. The specific indictors are summarized briefly below.

Why Was this Report Undertaken?

The Heinz Center convened a *Landscape Pattern Task Group* as part of its effort to improve upon the 2002 edition of *The State of the Nation's Ecosystems* report (2002 Report; Heinz Center 2002b). The 2002 Report contained just over 100 indicators distributed across six ecosystem chapters (i.e., *Coasts and Oceans*, *Farmlands*, *Forests*, *Fresh Waters*, *Grasslands and Shrublands*, and *Urban and Suburban Areas*), including a set of cross-cutting indicators—called *core national indicators*—which were meant to give the broadest view of the condition and use of U.S. ecosystems.

There have been three major foci of the Center's work since the 2002 Report: a study of the gaps apparent in the environmental monitoring system (Heinz Center 2005), two cross-ecosystem indicator refinement efforts constrained to a specific topic (non-native species and landscape pattern), and a cross-ecosystem indicator refinement effort targeting the report's core national indicators.

The 2002 Report included seven indicators within the category of landscape pattern, with two of these serving as placeholders given that a specific indicator was not proposed and with another three indicators defined yet lacking data[1]. Just two of the landscape pattern indicators were defined *and* had the necessary data available. Two system chapters (*Coasts and Oceans* and *Fresh Waters*) did not include landscape pattern indicators.

The project's Design Committee, which guides the project at the highest level, charged the Task Group to (a) recommend indicators in cases where a placeholder was included in the 2002 Report; (b) increase the scientific underpinnings of the suite of landscape pattern indicators; (c) determine whether it is possible—and sensible—to identify a suite of indicators that would be more consistent and uniform than the suite included in the 2002 Report, while still retaining important ecological distinctions; and (d) evaluate the decisions made independently by the Coasts and Oceans and Freshwater work groups during the process leading up to the 2002 Report that excluded indicators of landscape pattern for these systems.

What Process Was Used to Develop these Recommendations?

The Landscape Pattern Task Group drew on experts from industry, academia, environmental advocacy groups, and government (see listing inside front cover). The Task Group met four times from October 2003 to December 2004, with a large number of interactions between meetings. The Task Group's approach for addressing a particular indicator topic was:

1) Why is landscape pattern important in the context of a particular ecosystem type?
2) Does pattern matter in ways that are not already captured by the other indicators for the specific ecosystem type or the report, in general? In other words, would information about pattern add value to the overall suite of indicators?
3) What are the possible indicators that would address the question posed in item number 1 above for each ecosystem type? What are their supporting rationales? Note that these two questions were addressed without serious consideration of the availability of data.
4) Are the proposed indicators practical (or feasible)? If so, how might the indicator be tested (i.e., "proof of concept") in order to understand better its strengths and weaknesses? A final part of this was to assess whether or not acceptable data are available for these indicators.

Summary of the Task Group's Recommended Indicators.

The Task Group recommended eight new or revised indicators for the 2008 *State of the Nation's Ecosystems* report—2008 Report (Table 1). Each of these recommendations is described briefly below. In most cases, the full description of the indicator in the body of the report includes analyses of relevant data in order to provide worked examples of the indicators.

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[1] In these cases, land-cover data that could have been utilized for these indicators were available, however, the necessary time and funds were not available to have the necessary analyses performed.

Table 1: Summary of the Indicators Recommended by the Task Group

System	Proposed Indicator
Core National	Pattern of "Natural" Landscapes
Farmlands	Proximity of Cropland to Residences
	Patches of "Natural" Lands in the Farmland Landscape
Forests	Pattern of Forest Landscapes
Fresh Waters	In-Stream Connectivity
Grasslands & Shrublands	Pattern of Grassland-Shrubland Landscapes
Urban & Suburban Landscapes	Housing Density Changes in Low-Density Suburban and Rural Areas
	Patches of "Natural" Lands in the Urban and Suburban Landscape

Core National Indicator: Pattern of "Natural" Landscapes—This indicator describes what is adjacent to (or intermingling with) "natural" land cover. In addition, the new indicator highlights areas across the country that are made up of only "natural" land cover (e.g., forest, grassland, shrubland, wetland, and other freshwater components). The size of these areas that lack obvious signs of human modification (e.g., residential and commercial development, roads, and croplands) will be reported. This recommendation replaces a placeholder in the 2002 Report, which did not include a specific design for a cross-ecosystem, overarching indicator.

Farmlands: Proximity of Cropland to Residences—The recommended indicator evaluates the distance each small parcel of cropland (~ ¼ acre) is from a residence in agricultural landscapes. The percent of croplands within a range of distances from residences will be reported. It is worth noting that data on individual households are necessary for this indicator, however, such data are not expected in the near future for the nation's agriculturally-dominated landscapes.

The 2002 Report included an indicator dealing with this topic (Fragmentation of Farmland Landscapes by Development), however data were unavailable. This indicator had utilized a rather complex analysis formula, and the presentation of the previous indicator's results would have been dependent on being able to classify fragmentation into low, medium, and high classes. The Task Group recommends an indicator of a simpler design that explicitly describes the tension between agriculture and development.

Farmlands: Patches of "Natural" Lands in the Farmland Landscape—The new indicator would evaluate the proportion of small parcels of "natural" land cover (~ ¼ acre) within the *farmland landscape*[2] that have "natural" surroundings. While several analysis conditions are proposed, only a single condition is utilized for this report and the 2008 Report: the size of patches of adjacent "natural" parcels is reported. Like the other Farmland indicator, this one had a predecessor in the 2002 Report (Shape of "Natural" Patches in the Farmland Landscape) that lacked actual data. While the Task Group appreciated the merits of the predecessor's design, it

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[2] The farmland landscape refers to a series of polygons first defined by the Heinz Center in the 2002 Report (and updated in the 2008 Report) to represent areas across the country whose character is dominated by—but not exclusively covered by—cropland. It should be noted that the Heinz Center is considering refinements to the definition used for farmland landscapes and *urban and suburban landscapes* (see below) so that they might be more similar in construction.

was compelled to recommend a new indicator that, while capturing some of the same issues, would be more consistent with the overall strategy behind the group's full suite of recommended indicators.

Pattern of Forest Landscapes—The 2002 Report included an indicator, complete with national data, for this ecosystem type (Forest Pattern and Fragmentation). The Task Group considered revisions to this indicator mainly because of the feedback the Heinz Center received following the release of the 2002 Report. Specifically, the Task Group endeavored to (a) make the indicator more sensitive to "natural" heterogeneity (i.e., the intermingling of "natural" land-cover types, such as forest and shrubland in the West), and (b) evaluate whether or not roads, which are often discussed as potential fragmenting agents, could be incorporated in the indicator in a manner that would be consistent with the literature on road ecology. In addition, the Task Group sought to improve the indicator's presentation in order to facilitate communication of this indicator to a general audience.

The previous indicator reported the analysis of the surroundings of small parcels of forest (~ ¼ acre). Specifically, the density of forest within surroundings of different sizes was evaluated, and only those instances where the density was at least 90% were included. Thus, the percent of the nation's forests with small, medium, and large surroundings that had at least 90% forest cover was reported. Such data were perceived to be useful for distinguishing large tracts of essentially unbroken forest from much smaller, isolated patches of forest. The revised indicator utilizes such an analysis with small parcels meeting such criteria being classified as "core forest," with adjacent parcels being joined together into patches of "core forest."

The Task Group has recommended two major revisions to the 2002 Report's indicator. Rather than evaluating *only* the density of forest in the surroundings of any given parcel of forest, the new indicator considers other "natural" land cover as equal to forest land cover. This simplification is designed to distinguish between natural heterogeneity, which is common in the West, from intermingling croplands and development.

The second major revision is to acknowledge that roads are "non-natural" elements that should be explicitly included in a description of the structural pattern of landscapes.

In-Stream Connectivity—The Task Group recommends an indicator that evaluates connectivity in streams and rivers based on the presence of dams and diversions[3]. The indicator relies on the landscape being mapped into *subwatersheds*, which define small, hydrologically-connected elements of the landscape. For a given subwatershed, the indicator has a value of zero if a dam or diversion is present within it. Otherwise, the indicator takes on the value of the distance from the outlet of the subwatershed to the first downstream dam or diversion. Cases in which the stream or river flows freely to its natural end-point (e.g., the ocean) will be highlighted. A final note is that the indicator will provide an accounting of subwatersheds with and without dams (or diversions)—both in graph and map form. There was no indicator in the 2002 Report in the landscape pattern category.

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[3] Whether or not a diversion affects connectivity along a stream or river is dependent on the relative size of the diversion compared to stream flow. Data are not available nationally for diversions, and, in part because of this, the Task Group did not define what size diversion should be considered by this indicator.

Pattern of Grassland-Shrubland Landscapes—The Task Group recommends an indicator identical in design to the Pattern of Forest Landscapes indicator (see above).

The 2002 Report included a specific indicator describing the size of grassland and shrubland patches (*Area and Size of Grassland and Shrubland Patches*), however data could not be processed in time for inclusion in the report. The Task Group recommends that this new indicator replace the earlier patch size indicator. The Task Group makes this recommendation that is consistent with the overall indicator suite of landscape pattern indicators, however, knowing that it did not benefit from a "critical mass" of participation from grassland-shrubland experts.

Thus, the differences with the indicator proposed in the 2002 Report are (a) patches of "core grassland" or "core shrubland" will be reported rather than simply grassland or shrubland patch sizes, (b) the indicator will be sensitive to natural heterogeneity, and (c) and it will incorporate roads as "non-natural" landscape elements. The indicator data would be reported based on both grassland area and shrubland area, consistent with the indicator in the 2002 Report.

Urban and Suburban Areas: Patches of "Natural" Lands in the Urban and Suburban Landscape—The indicator would be modeled directly after the analogous indicator in the Farmlands chapter (*Patches of "Natural" Lands in the Farmland Landscape*), evaluating the proportion of parcels of "natural" land cover (~ ¼ acre) within urban and suburban areas that have "natural" surroundings. As for the Farmlands indicator, a simplifying case was used for this report and the 2008 Report: the size of patches of "natural" parcels is reported without requiring specific conditions surrounding each of these small parcels. This simplification makes the indicator equivalent to the one that was included in the 2002 Report (*Patches of Forest, Grassland and Shrubland, and Wetlands*).

Urban and Suburban Areas: Housing Density Change in Low-Density Suburban and Rural Areas— The indicator will evaluate the number of new houses added in an area over a time period relative to the housing density in that area at the beginning of the period. It will, thus, highlight whether new development is occurring in areas of low or high densities. A placeholder was included for this topic in the 2002 Report.

Coasts and Oceans: A Promising Outlook—As mentioned above, the 2002 Report did not include an indicator of landscape (or seascape) pattern in the Coasts and Oceans chapter. The Task Group concluded that there was sufficient promise of developing such an indicator and two workshops of experts with knowledge in this area were convened. Several candidate metrics have been identified, although considerable work would still be needed to refine one or more of these ideas.

In Summary: Recommendations for the 2008 *State of the Nation's Ecosystems*.

Within this report are proposals that have lead to a fully revised and improved suite of indicators for reporting on landscape pattern on a national scale. These indicators build off of the most recent understandings of science, although by their broad nature, they cannot be expected to capture all impacts of changing landscapes on biota and/or on the services ecosystems provide to people. Each indicator has been designed to characterize the changing structure of landscapes, with the expectation that these changes in structure are ultimately linked to changes in ecosystem function.

ABOUT THE HEINZ CENTER

Established in December 1995 in honor of Senator John Heinz, The H. John Heinz III Center for Science, Economics and the Environment is a nonprofit, nonpartisan institution dedicated to improving the scientific and economic foundation for environmental policy through multisectoral collaboration. Focusing on issues that are likely to confront policymakers within two to five years, the Center fosters collaboration among industry, environmental organizations, academia, and government in each of its program areas and projects. It uses the best scientific and economic analyses to develop viable options to solving problems, and its findings and recommendations are widely disseminated to public and private sector decision makers, the scientific community, and the public.

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DESIGN COMMITTEE FOR THE STATE OF THE NATION'S ECOSYSTEMS PROJECT

William C. Clark, Chair, Harvard University
Ann M. Bartuska, USDA Forest Service
Rosina Bierbaum, University of Michigan
Bradley Campbell, New Jersey Department of Environmental Protection
Norman L. Christensen, Duke University
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P. Patrick Leahy, American Geological Institute (formerly U.S. Geological Survey)
Rebecca Lent, National Oceanic and Atmospheric Administration
Al Lucier, National Council for Air and Stream Improvement, Inc.
Suzanne Iudicello Martley, Independent Marine Conservation Writer
Steven Murawski, National Oceanic and Atmospheric Administration
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Gordon Orians, University of Washington
Don Parrish, American Farm Bureau Federation
Duncan Patten, Montana State University
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Douglas P. Wheeler, Hogan and Hartson, LLP
John A. Wiens, PRBO Conservation Science (formerly The Nature Conservancy)
Terry Young, Environmental Defense Fund

Agency Liaisons
Rich Guldin, USDA Forest Service
Laura Nielsen, U.S. Environmental Protection Agency
Denice Shaw, U.S. Environmental Protection Agency

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CHAPTER 1: INTRODUCTION

The Context for this Report: The State of the Nation's Ecosystems Project

In September 2002, the Heinz Center released *The State of the Nation's Ecosystems* (hereafter referred to as the 2002 Report) which laid the foundation for periodic, high-quality, non-partisan reporting on the condition and use of our nation's ecosystems.

This report was developed over a five-year period by experts from business, environmental, academic, and federal, state, and local government institutions. The goal was to select a set of indicators that would provide a strategic view of key aspects of ecosystem condition, to serve as the basis for periodic reporting to decision makers and the public.

The report includes indicators for each of the six principal ecosystem types in the U.S. (coasts and oceans, farmlands, forests, fresh waters, grasslands and shrublands, and urban and suburban areas), and for the nation as a whole. These 103 indicators describe 10 major characteristics, which can be grouped into four broad categories: the basic dimensions of the system, chemical and physical conditions, biological components, and human uses (See Table 2).

Table 2: Ecosystem characteristics and indicator focus in *The 2008 State of the Nation's Ecosystems*

Ecosystem Characteristic	**What Do The Indicators Measure?**
Extent and Pattern	
Extent	How much area does an ecosystem or land cover type occupy?
Pattern	What are the shapes and sizes of patches of an ecosystem type, and how are they intermingled with one another?
Chemical and Physical Conditions	
Nutrients, Carbon, Oxygen	How much nitrogen, phosphorus, oxygen and carbon are found in different systems?
Chemical Contamination	How many synthetic compounds and heavy metals are found in ecosystems, and how often do these compounds exceed regulatory or advisory thresholds? (For urban / suburban areas, we also include air pollution from ozone in this category.)
Physical	What is the condition of key aspects of the physical makeup of an ecosystem, such as the temperature of the water or the amount of salt in the soil?
Biological Components	
Plants and Animals	What is the status of native and non-native plant and animal species?
Communities	What is the condition of the plant and animal communities that make up an ecosystem?
Ecological Productivity	What are the trends in plant growth on land and in the water?
Goods and Services	
Food, Fiber, and Water	How is the amount and quality of key ecosystem products changing over time?
Recreation and Other Services	How often do people take part in outdoor recreation activities, and what other services, such as soil building and flood protection, are provided by natural ecosystems?

The Heinz Center released the next edition of *The State of the Nation's Ecosystems* in 2008. Not only is updated data included in the 2008 edition, but a considerable number of indicators have been revised and improved. The indicators included in this report represent one of the major indicator revision processes; a similar effort was undertaken to improve indicators for non-native species and the suite of overarching, cross-ecosystem indicators termed the "core national indicators."

The Landscape Pattern Task Group: Background and Charge

Indicators of "system dimensions" (now titled "extent and pattern") for the various ecosystem types describe both the amount of the ecosystem, or extent, and, for the terrestrial systems, a variety of landscape pattern features (see Table 2). Indicators of pattern typically measured the degree to which one land-cover type was intermingled with others. Seven indicators addressed landscape pattern, two of which were completely undefined and three of which did not have national data available (see Table 3). Please refer to the 2002 *State of the Nation's Ecosystems* (Heinz Center 2002b) for a complete discussion of each of these indicators.

It is clear from a brief review of Table 3 that the suite of pattern indicators from the 2002 Report are as different as they are similar. These indicators were selected by work groups focused on specific ecosystems (e.g., forests) rather than by a group of experts similarly conversant in issues of landscape ecology who were trying to develop a coherent suite of landscape pattern indicators. Few attempts were made to force uniformity across systems, however, the project's Design Committee has recognized that it would be beneficial to increase the consistency and coherence of this group of indicators in order to be able to communicate broad trends clearly to policymakers and the public. Indeed, reviewing several suites of indicators, including those for non-native species and landscape pattern, from a cross-ecosystem perspective has been one of several primary objectives of the State of the Nation's Ecosystems project prior to the release of the next major edition of the report scheduled for early 2008.

Further, it is critical that the individual indicators be as meaningful as possible. For example, the 2002 Report's Forest Pattern and Fragmentation indicator has been particularly difficult to explain to a lay audience—including our target audience of high-level opinion leaders and policy makers. In this case, more understandable indicator concepts were dropped due to their controversial nature.

In 2003, the Heinz Center convened a panel of experts (see inside front cover) to review this particular suite of indicators. One of the group's first decisions, was to adopt the title of "Landscape Pattern Task Group," rather than "Fragmentation Task Group," which had been proposed by the Heinz Center. This non-trivial change was made because of a recognition that fragmentation is a type of landscape pattern, and it carries with it normative connotations. That is, the same pattern on a landscape may be interpreted positively or negatively, depending on one's own values and perspective, yet if the pattern is described as "fragmentation," it immediately makes people think that the pattern described has only negative ecological implications.

The Task Group was challenged to:

- provide recommendations for indicators for which only a placeholder had been included in the 2002 Report.

- improve the scientific basis, where necessary, of the various indicators, including the development of a framework for addressing landscape pattern indicators in a national report of ecosystem condition and trends. In developing this framework, the group had to grapple with the effects that a wide variety of human activities can have on the pattern of landscapes.

- determine whether it is possible—and sensible—to identify a suite of indicators that would be more consistent and uniform than the suite included in the 2002 Report, while still retaining important ecological distinctions. In general, the group recommended changes along these lines as part of a fully-revised suite of landscape pattern indicators for inclusion in the 2008 *State of the Nation's Ecosystems* report.

- evaluate the decisions made independently by the Coasts and Oceans and Freshwater work groups during the process leading up to the 2002 Report that excluded indicators of landscape pattern for these systems. These omissions were conscious choices made by the groups, but the project's Design Committee wanted the Task Group to provide feedback from the landscape ecology community. This report details a new indicator proposal for in-stream connectivity in freshwater systems, and a still-ongoing process has been undertaken to develop one or more candidate indicator for coastal areas.

Table 3: Landscape Pattern Indicators in 2002 *State of the Nation's Ecosystems*

Indicator Title	Description	Development & Data Status	Page in 2002 Report
Core National Indicators			
Fragmentation and Landscape Pattern	The concept is that this indicator will capture fragmentation across multiple ecosystem types.	Indicator not defined	Indicator, p. 44 no Tech. Note
Coasts and Oceans			
no indicator			
Farmlands			
Fragmentation of Farmland Landscape by Development	The degree to which suburban development and other built-up areas break up the farmland landscape.	Indicator defined, data available but not processed	Indicator, p. 93 Tech. Note, p. 231
Shape of "Natural" Patches in the Farmland Landscape	The shape of patches of "natural" lands (i.e., forests, grasslands and shrublands, wetlands, and Conservation Reserve Program (CRP) lands) described based on perimeter-to-area ratios. There will be three classes of patch shape: compact (e.g., circular), intermediate, and elongated (e.g., narrow rectangle).	Indicator defined, data available but not processed	Indicator, p. 94 Tech. Note, p. 232
Forests			
Forest Pattern and Fragmentation	Conveys whether or not "points" in forests are surrounded by little, some, or a lot of forest. In reality each point is a pixel of satellite data (30 m x 30 m). Points surrounded by at least 250 feet of mostly forested land have a forested "immediate" neighborhood. Points surrounded by about ¼ mile of mostly forested lands are considered to have a forested "local" neighborhood. And, points surrounded by 2.5 miles of forest have a forested "larger" neighborhood.	Indicator defined and data available	Indicator, p. 120 Tech. Note, p. 240
Fresh Waters			
no indicator			
Grasslands and Shrublands			
Area and Size of Grassland and Shrubland Patches	The fraction of grassland area and shrubland area that is in patches of different sizes. Patches of grassland or shrubland are identified separately, and the total area occupied by patches of a certain size will be reported as a percentage of the total area of either grasslands or shrublands.	Indicator defined, data available but not processed	Indicator, p. 163 Tech. Note, p. 258
Urban and Suburban Areas			
Patches of Forest, Grassland and Shrubland, and Wetlands	How much of the "natural" area within urban and suburban lands is in patches of varying size, from less than 10 acres to greater than 10,000 acres. "Natural" areas include forests, grasslands and shrublands (including most pasturelands—especially in the west), and wetlands.	Indicator defined and data available	Indicator, p. 183 Tech. Note, p. 266
Suburban/Rural Land Use Change	The concept is that this indicator will describe the pattern and intensity, or density, of development, both at the outer edge of suburban development around cities, and in rural areas that, despite the lack of a large town center, are growing rapidly toward suburban densities.	Indicator not defined	Indicator, p. 182 No Tech. Note

Task Group's Approach

In general, the group agreed that a key question to focus on initially was: *why does pattern matter?* The group agreed to begin with an exploration of the key aspects of ecosystem condition or quality that members believe are related to landscape pattern. These include "habitat quality" (which was strongly relied upon as the rationale for indicators in the 2002 report), but also a variety of physical and biogeochemical processes, and human issues such as agricultural productivity and livability.

This initial scoping exercise was followed by exploration of the nature and strength of the scientific evidence that relates changes in these characteristics to pattern in general and specific pattern metrics in particular. The group agreed that its approach for developing indicators of landscape pattern should be guided by four questions:

1) Why is landscape pattern important in the context of a particular ecosystem type?

2) Does pattern matter in ways that are not already captured by the other indicators for the specific ecosystem type or the report, in general? In other words, would information about pattern add value to the overall suite of indicators?

3) What are the possible indicators that would address the questions posed in item number 1 above? What are their supporting rationales? Note, these two questions were addressed without serious consideration for the availability of data.

4) Are the proposed indicators practical (or feasible)? If so, how might the indicator be tested (i.e., "proof of concept") in order to understand better its strengths and weaknesses? A final part of this was to assess whether or not acceptable data are available for these indicators.

How Have the Task Group's Recommendations Been Used by the Heinz Center?

As discussed above, the Task Group was commissioned by the project's Design Committee to undertake a thorough review of the landscape pattern indicators in the 2002 *State of the Nation's Ecosystems* report. All of the Task Group's recommendations have been endorsed by the Design Committee for use in the 2008 *State of the Nation's Ecosystems* report. In order to inform their deliberations, the Design Committee engaged a broad suite of stakeholders, including members of the ecosystem working groups from the 2002 Report and an array of external reviewers, soliciting feedback on how the revised—or new—indicators fit within the suite of indicators for the individual ecosystem types.

Background on the Issues

Human omnipresence on the landscape, in general, leads to an altered environment ranging from changed land uses to major changes in biogeochemical cycles. The purpose of developing ecological indicators such those presented here is to highlight and track changes in the environment that are of ecological significance. The goal of this project is to report ecological indicators that have a direct relevance in policy making. This background section is not designed to be a treatise on the state of scientific research on landscape ecology. Rather, this section is intended to provide adequate background on the issues, with references made to some of the many recent reviews of the various topics discussed in the report

The Task Group was specific in wanting this report (and the individual indicators) to broadly address the topic of landscape pattern, instead of focusing solely on fragmentation. The rationale is that fragmentation is a type of pattern, and is normative in the sense that its use connotes a negative ecological process—patterns on the landscape may be viewed positively or negatively depending on one’s perspective.

Structure, Not Function—In general, natural (e.g., fire and wind) and anthropogenic (e.g., land use change) processes can have lasting impacts on the pattern observed on landscapes. Yet, the impacts of changing landscape patterns on habitat quality are a matter of great contention. The source of this contention appears to be firmly rooted in the fact that different species of plants and animals respond to altered landscapes differently. This fact is further complicated because *The State of the Nation’s Ecosystems* is a coarse-grained approach, meaning that a single indicator, or at most two, needs to represents the issue of landscape pattern for an entire ecosystem type (e.g., grasslands and shrublands) rather than being targeted at a single species in a single situation (e.g., salamanders in western coniferous forests).

Most of the landscape pattern indicators in the 2002 Report (see Table 3) were described as being measures of habitat quality. That is, these indicators make the following types of statements:

> The size and shape of these often small and isolated remnants [of natural lands], along with restored conservation areas (e.g., CRP land), directly influence the amount and type of ecosystem services provided. Habitat fragmentation may create new kinds of habitats that are colonized by generalist native species or exotic species. For example, small patches and long narrow ones may have little or no “interior” habitat. Since some species thrive only in interior habitat—where there is a relatively large and contiguous area of forest, grassland, or other natural cover (see the forest fragmentation indicator), small narrow areas may not provide habitat for these species. On the other hand, narrow strips may function quite well for erosion and sediment control. (Farmlands, p. 94)
>
> "Forest fragmentation" describes the degree to which forested areas are being broken into smaller patches and interspersed with nonforest areas. Research has shown that forest close to nonforest cover is often warmer and drier, more likely to be affected by wind, and more likely to be invaded by non-native species. In addition, forest animals that live near developed areas, farmlands, or roads are more likely to be affected by collisions with cars, increased hunting pressure, noise, lights, predation by cats and dogs, etc. (Forests, p. 120)

However, the literature on the direct link between landscape fragmentation and ecological impacts is equivocal (e.g., Andren 1994; Chalfoun et al. 2002; Debinski and Holt 2000; Forman and Alexander 1998; Lahti 2001; Lugo and Gucinski 2000; Saunders et al. 1991; Trombulak and

Frissell 2000; Villard 2002). For this reason, the presentations in the 2002 Report are presented with caveats.

Perhaps the larger issue is that there are many other aspects of ecological structure (e.g., vegetation types, age classes present, seral stages represented, etc.) that cannot be captured by only describing structural aspects of landscapes. Even if we were able to describe habitat structure fully using a suite of indicators, this information could not be used to make *a priori* conclusions about ecosystem function. Other inputs (e.g., species richness, population abundances, etc.) would be necessary to approach an understanding of ecosystem functioning. Thus, realistic expectations for any single ecological indicator, as well as the full suite of landscape pattern indicators, are warranted.

The Effects of Pattern on Potential Habitat—The structural pattern of “natural” ecosystem types (forests, grasslands, and shrublands) is considered by two indicators in this report. The general approach is to estimate the degree to which the landscape in question is found on the landscape in contiguous blocks of “natural” land cover. The overarching assumption made is that a landscape completely covered with a given land cover type (e.g., forest) provides potential habitat uniformly across it. This is a major simplification, in part because other land-cover types (e.g., grassland) may provide a similar level of potential habitat when found in that landscape, whereas another type (e.g., cropland) may not (see discussion on p. 18). It is also a major simplification because information on land cover provides only partial information about the potential value of land as habitat. At a minimum, adding information about land use, for example, would enable a richer analysis

Landscapes are altered in three main ways: reductions in the total habitat area, increases in isolation of the resulting remnants, and the creation of edges where remnant areas abut modified ecosystems. Each of these changes in turn influences a range of population, community and ecosystem processes that may affect biodiversity (Kupfer et al. 2006). Many long-standing theories concerning the effects on forest biodiversity stem from applications of island biogeography theory, which states that the number of species on oceanic islands is a function of extinction rates (which were linked to island size and habitat heterogeneity) and immigration rates (which were linked to the arrival of potential colonists and thus island isolation) (Macarthur and Wilson 1967). Large islands located near the mainland were hypothesized to maintain the greatest number of species because of their size and proximity to colonization sources while small, isolated islands had the fewest species. Ecologists subsequently drew parallels between oceanic islands and terrestrial habitats that had been fragmented by human land uses (i.e., forested ecosystems as areas of suitable habitat embedded in an uninhabitable matrix of non-forested uses) and began to study the relationships among biodiversity, remnant forest area and forest patch isolation (e.g., Diamond 1975; Simberloff and Abele 1976; Whitcomb et al. 1976).

The ensuing debate over the validity of applying island biogeography theory to terrestrial habitats is lengthy and has been reviewed elsewhere (see for example, Kupfer et al. 2006). For example, a simple forest / non-forest dichotomy may be an incomplete description because not all non-forested habitat is uniformly unsuitable as habitat nor serves as an impenetrable barrier to the dispersal of certain forest taxa (see below). Studies of mosaic landscapes containing a range of old-growth forest, successional habitats, and agriculture, for example, exemplify how landscapes can represent a range of conditions from deforestation to varying degrees of forest degradation in otherwise “intact” forest. Nonetheless, the basic tenet of island biogeography (i.e., the importance of habitat amount and pattern) and, thus, the application of landscape indicators based on them, are still widely accepted, and may be very useful in, for example, the design of preserves.

Reasons to Treat Other "Natural" Land Cover As Equivalent Potential Habitat—This discussion is oriented to the Pattern of Forest Landscapes indicator, although is presumably generally applicable to the companion Grassland and Shrublands indicator (see p. 51) as well as the Pattern of "Natural" Landscapes indicator (p. 20). One of the primary criticisms of the previous forest fragmentation indicator was that it was unduly sensitive to natural heterogeneity of forests in the arid western U.S. because all non-forested land-cover types were treated equally. A non-continuous forest pattern may be the result of either: 1) discrete activities or events, such as road construction, logging, conversion to agriculture, or wildfire, or 2) spatial heterogeneity in environmental conditions, such as variations in soil moisture.

Ecologically, the effects of intensive agriculture, logging, or conversion of land to human habitation differ greatly from natural heterogeneity in a number of important ways. Some forest species utilize adjacent non-forested habitats for feeding or other activities and may not find necessary resources in certain kinds of human-dominated land uses. Studies of avian populations have also cited the importance of an expanded resource base in disturbed habitats as a factor determining the presence of specific species in forest remnants, noting that some species may be able to compensate for a loss of their natural forest habitat by moving into other habitat types (Norton et al. 2000; Sisk et al. 1997). Similarly, plant and animal movement across fragmented landscapes depends not only on the species' dispersal ability and the isolation and characteristics of suitable patches of habitat but also on the permeability of the intervening non-forested landscape (Murphy 2004). While the quality and usefulness of non-forested land used as both habitat and movement corridor is more a function of their characteristics than the nature of the disturbance *per se*, separating those habitats associated with distinct human land use conversion provides one potentially useful manner for recognizing this distinction.

CHAPTER II: PROPOSED INDICATOR SUITE

The proposed indicators describe the *structure* of landscapes based on how the various elements of the landscape intermingle. As discussed in the Chapter 1, conclusions about the *function* of landscapes as habitat are related to the structure of these landscapes, but function is ultimately governed by many factors. This section begins with a conceptual model tied to the reporting framework of *The State of the Nation's Ecosystems*, followed by both a summary of the proposed indicators and detailed examinations of each indicator. It is worth emphasizing that the presentation of the proposed indicators are thorough from a design perspective, however, some of the data presented are of a proof-of-concept nature.

The remainder of this chapter is devoted to detailed presentations of the eight indicator proposals, which are summarized in Table 4. It should be noted that the Task Group also urged the use of indicators that would describe transitions from one land-cover type to another (e.g., "natural" to cropland, or cropland to forest), both broadly and at the ecosystem level when appropriate (e.g., capturing transitions between grasslands and shrublands). This concept has been included in a revised core indicator of ecosystem extent for the *2008 State of the Nation's Ecosystems* report.

Table 4: Summary of the Indicators Recommended by the Task Group

System	Proposed Indicator
Core National	Pattern of "Natural" Lands
Coasts and Oceans	Pattern of Coastal Areas
Farmlands	Proximity of Cropland to Residences
	Patches of "Natural" Lands in the Farmland Landscape
Forests	Pattern of Forest Landscapes
Fresh Waters	In-Stream Connectivity
Grasslands and Shrublands	Pattern of Grassland-Shrubland Landscapes
Urban and Suburban Landscapes	Housing Density Changes in Low-Density Suburban and Rural Areas
	Patches of "Natural" Lands in the Urban and Suburban Landscape

Core National Indicator: Pattern of "Natural" Landscapes

The Task Group strove to develop a core national indicator (see Box 1) that would resonate with the indicators in the various ecosystem chapters when it became clear that simply aggregating the values of indicators across the ecosystem chapters would not be feasible. As discussed earlier, the 2002 *State of the Nation's Ecosystems* highlighted the need for a core national indicator of landscape pattern, but no formal proposal was included.

Box 1—Core National Indicators. *The State of the Nation's Ecosystems* report has a suite of "core national indicators" that are meant to report on key aspects of ecosystem condition and use across the various ecosystem types. In general, there are two options for such a core indicator. If the report contains several similar ecosystem-specific indicators, then the core indicator can serve to "roll up" the data from these more detailed indicators, thereby presenting an overarching synthesis. If, however, the nature of the topic involved dictates that the indicators for different ecosystems are dissimilar, then the core indicator cannot simply be used to synthesize across systems. In this case, which is the situation presented here for the landscape pattern indicators, an indicator should be chosen that applies to as many of the systems as possible and captures issues that cross ecosystem-type boundaries.

What Is the Task Group Recommendation? The Task Group recommends an indicator that describes the surroundings of small parcels (1/4 acre), or pixels, of "natural" land cover. In other words, are "natural" pixels surrounded by other "natural" lands, or are there intermingling agricultural and developed lands? Each pixel of "natural" land cover is assigned a value based on the composition of its surroundings (~240 acres) ranging from "core natural" (100% "natural" in its surroundings) to less than 60% "natural," with several classes in between, such as at least 80% "natural" with at least 10% developed lands. In addition, adjacent "core natural" pixels are grouped together into patches, and the size of these patches are reported. Although the terminology is not perfect, "natural" is taken to represent forest, grassland, shrubland, wetlands, and other waters—both freshwater and coastal.

The values reported for this indicator will depend greatly on definitions. For example, indicator results will vary based on number of surrounding pixels that are analyzed, not to mention the geometry of these surrounding pixels. The Task Group recommends using a square analysis tool, or window, approximately 1-km on a side, and augmenting these primary data with smaller and larger analysis windows if possible[4]. Also, what constitutes "development" will have a key impact on the indicator values. The Task Group's interest is that this indicator should be extremely sensitive to all types of human development. Land-cover data will be used to represent residential and commercial development; however, as with other indicators in this report (e.g., Proximity of Cropland to Residences, p. 30), more refined data on the location of low-density housing would make this indicator more sensitive. It is proposed that available data be used on roads—both large and small, but excluding unpaved roads; improvements in these data over time will further improve the sensitivity of this indicator. In addition, future implementation of this indicator would benefit from detailed land-use data that would help to separate lands that are more natural from, for example, tree farms that are heavily managed and grasslands that are heavily grazed.

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[4] Note that, because of time and resource constraints, additional analysis window sizes could not be added to the 2008 edition of *The State of the Nation's Ecosystems*.

Why Do We Care About This Indicator? This indicator will describe very broad patterns of how developed and agricultural lands are intermingled with “natural” land-cover types. These patterns have multiple consequences and, thus, multiple reasons to report them. They include the influences on habitat quality: the *structure* of “natural” landscapes is important given its potential link with the *function* of these landscapes ecologically. The intermingling of different land-cover types is a simple way to describe landscape structure. Whether or not a particular landscape structure leads to better quality habitat typically varies by species—the degree to which an organism finds a landscape acceptable habitat depends on its level of mobility and other factors.

Speaking very broadly, it is fair to say that interior forest species (i.e., species that are sensitive to edge effects), for example, will find better habitat in large, unbroken tracts of forest as compared to forest that has significant amounts of development and/or cropland intermingled within it. Further, except for those species that can only tolerate forested conditions, species probably find better habitat in areas comprised of a mix of “natural” lands than they would in areas with large amounts of development or agricultural lands adjacent or intermingled. Clearly, there are exceptions, such as white-tailed deer that tend to prosper when woodlands abut regions of development.

Broad landscape patterns affect water quality: higher levels of development, including roads, or agricultural land in a region or watershed are often associated with increases in nutrients, contaminants, siltation, and physical changes to streams and other water bodies. In addition, human development can have chemical and physical effects on their surroundings, such as increases in temperature and dryer soils at the boundary between “natural” and developed lands.

Pattern changes are consequential from a social perspective: the visual quality of landscapes is directly related to the degree of homo- or heterogeneity of a region, and debates over “sprawl” often involve visual as well as ecological and economic consequences of such pattern changes.

Finally, this indicator describes patterns that relate to the accessibility of “natural” areas to humans, which has implications in terms of recreation, hunting, spread of non-native species, etc. Large intact “natural” areas are sought out by hikers seeking a wilderness experience, they serve as refuges for other animals, and areas with higher human access often have higher levels of non-native species.

What Are the Details of the Indicator Design? The recommendation is to use an indicator that measures the composition of different land-cover types in the surroundings of each pixel of “natural” land cover. Starting with a land-cover map (see Box 2), pixels would be grouped into “natural” and “non-natural” classes. It is recommended that the land-cover map be augmented with a current map of paved roads, such as the map available through ESRI (www.esri.com); however, note that some argue that this step is not necessary because the latest land-cover map (2001 NLCD) may already include many paved roads.

The data analysis involves a “moving window” approach (see Box 3) to determine the composition of different land-cover types in the surroundings of each “natural” land-cover pixel.

The window would be square and of a fixed size[5], and the compositional class (see Table 5) of different pixels in the window would be assigned to the pixel at the center of the moving window. As mentioned above, an analysis window of a single size (~1 km^2) was used for the 2008 edition of *The State of the Nation's Ecosystems* report. This window size was chosen as a size that would generally represent an acceptable buffer size. Of course, some organisms would be fine with a much narrower buffer of "natural" land cover, whereas other species might be affected even with a buffer of about ½ km. In this context, the term "buffer" refers to the nominal distance from the center of the "natural" pixel of interest to the edge of the analysis window.

Table 5: Compositional Classes for Core National Indicator

	% of Designated Pixels in Surroundings		
Class Name	**"Natural" (N)**	**Cropland (C)**	**Developed (D)**
"Core Natural"	100		
N ("Natural")	at least 80	less than 10	less than 10
Nc ("Natural"/Cropland)	at least 80	at least 10	less than 10
Nd ("Natural"/Developed)	at least 80	less than 10	at least 10
Ncd ("Natural"/Cropland/Developed)	at least 60	at least 10	at least 10
"Some Natural"	less than 60	at least 40% of cropland and/or development	

Note that the developed category includes roads (and possibly railroads in the future), which as discussed above, requires augmenting land-cover maps with one or more databases on these linear features. Figure 1 shows three land-cover types as they might show up in a square moving window with 9 cells on each side. This sample landscape, as viewed by a 9x9 moving window, would carry the "Nc" classification because it contains over 80% "natural," more than 10% cropland pixels and fewer than 10% developed pixels (see Table 5). When repeated for every "natural" pixel in a given land-cover map, data can be summarized at various levels, such as state, region, or nationally.

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[5] Riitters and colleagues have generally used a 9x9 window, regardless of the grain (i.e., pixel dimension) of the data, in order to have an adequate number of pixels statistically (see Riitters et al. (2000); the proposal herein uses an even larger (33x33) window).

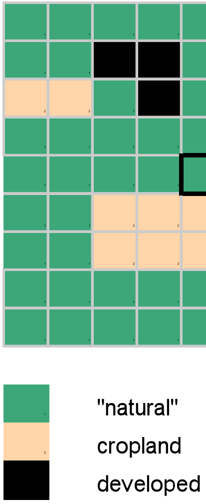

Figure 1: A 9x9 window of a sample landscape with three different land-cover types.

Box 2—Land-cover Maps: A Foundation for the Indicators. Many of the indicators described in this report rely on an approach that utilizes land-cover data in the form of a grid. Such data cover an area of interest using a set of non-overlapping "pixels," each of which can be assigned one of several classifications. While the indicators described in this report are not specific to any one data set, the expectation is that the National Land Cover Dataset (NLCD), a product of the Multi-Resolution Land Characteristics Consortium (MRLC; www.mrlc.gov), will be most appropriate for the proposed indicators. The NLCD covers the country with a grid of 30 meter (~100 ft.) pixels, each of which is assigned one of about 20 land-cover classifications (see Appendix A). These data are entered into a Geographic Information System (GIS), where other features of the landscape (e.g., roads) can be added and analyses performed.

How Will the Indicator Data Be Presented? Data have been analyzed for the conterminous U.S., both for this report and for the 2008 Report by analysts with the USDA Forest Service and the U.S. Environmental Protection Agency. The land-cover map combined the 2001 NLCD with the ESRI roads database (Figure 2). A map of "natural" pixels could be shown (Figure 3), with the underlying data graphed, both regionally and nationally (Figure 4). Ideally, a map of "core natural", as well as the other landscape patterns, would be presented[6] as well as being available in an interactive format via the internet.

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[6] Note that electronic data associated with these analyses were corrupted thereby preventing a map from being generated for this report.

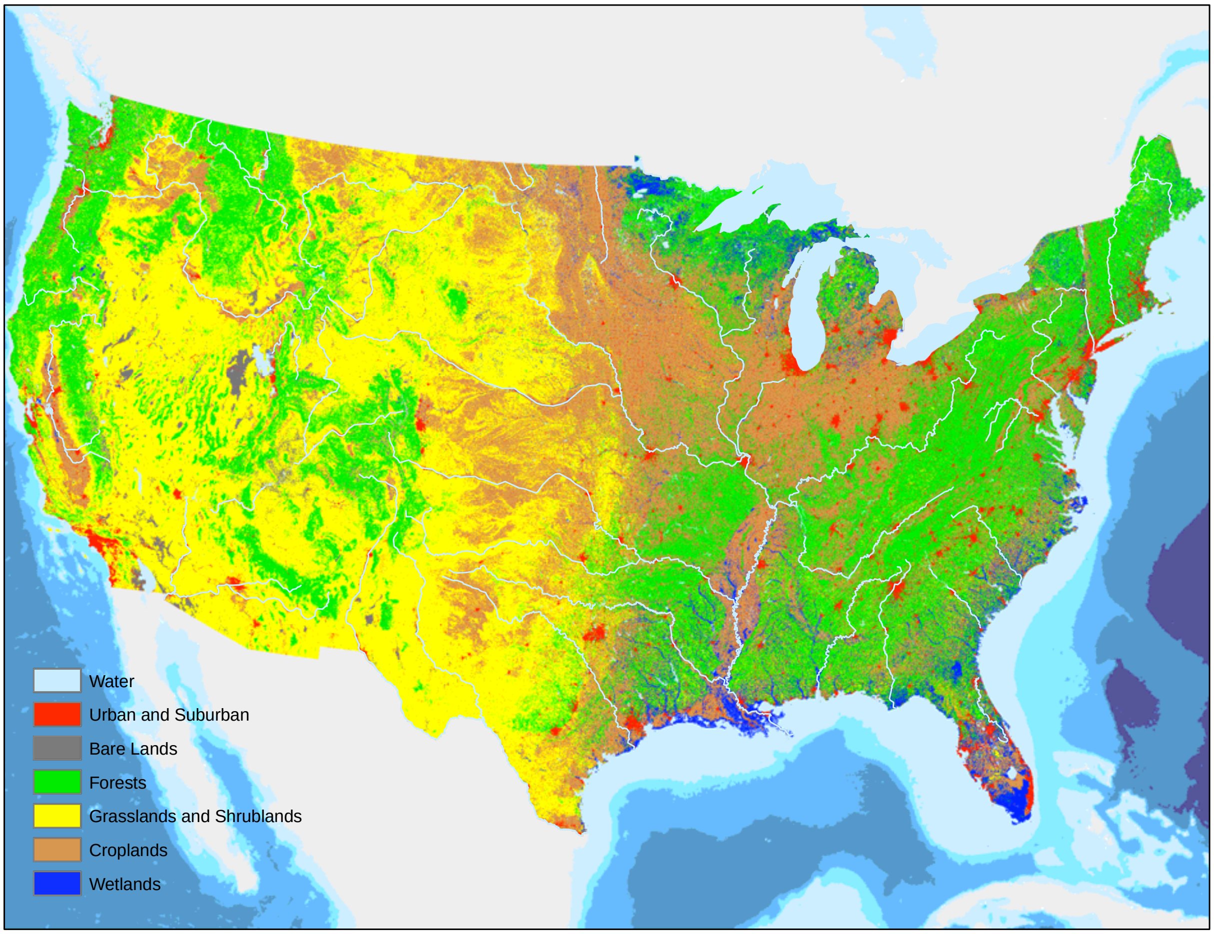

Figure 2: 2001 Land-cover map for conterminous U.S. Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

Box 3—"Moving Window" Analyses. Starting with a land-cover map (see Box 2), a program is written to evaluate a fixed number of pixels surrounding any one given pixel, termed the "focal pixel." Generally, a square geometry is used, meaning that the program selects a group of pixels that constitute a square and have the focal pixel at the center of the square; the square of pixels is often referred to as a "window." These windows are commonly described based on the number of pixels that make up a side (e.g., 3 x 3, 9 x 9, etc.).

Within the window, a specific analysis is performed, such as determining the number of these pixels sharing a given land-cover type. This result is then associated with the focal pixel in a new grid-based map. The analysis is repeated such that every pixel is treated as a focal pixel, and a value describing its immediate surroundings (as defined by the "window") is determined for it in the new grid-based map—hence the term "moving window." More complex analyses are possible, such as evaluating the number of different types of edges within the collection of neighboring pixels.

The main advantage of the moving window approach is that it describes the "context" of a point in the landscape relative to the larger landscape. A variety of moving window sizes can—and should—be used to understand how the variable of interest varies across scales. However, communicating the results of such a complex analysis to a general audience can be very challenging.

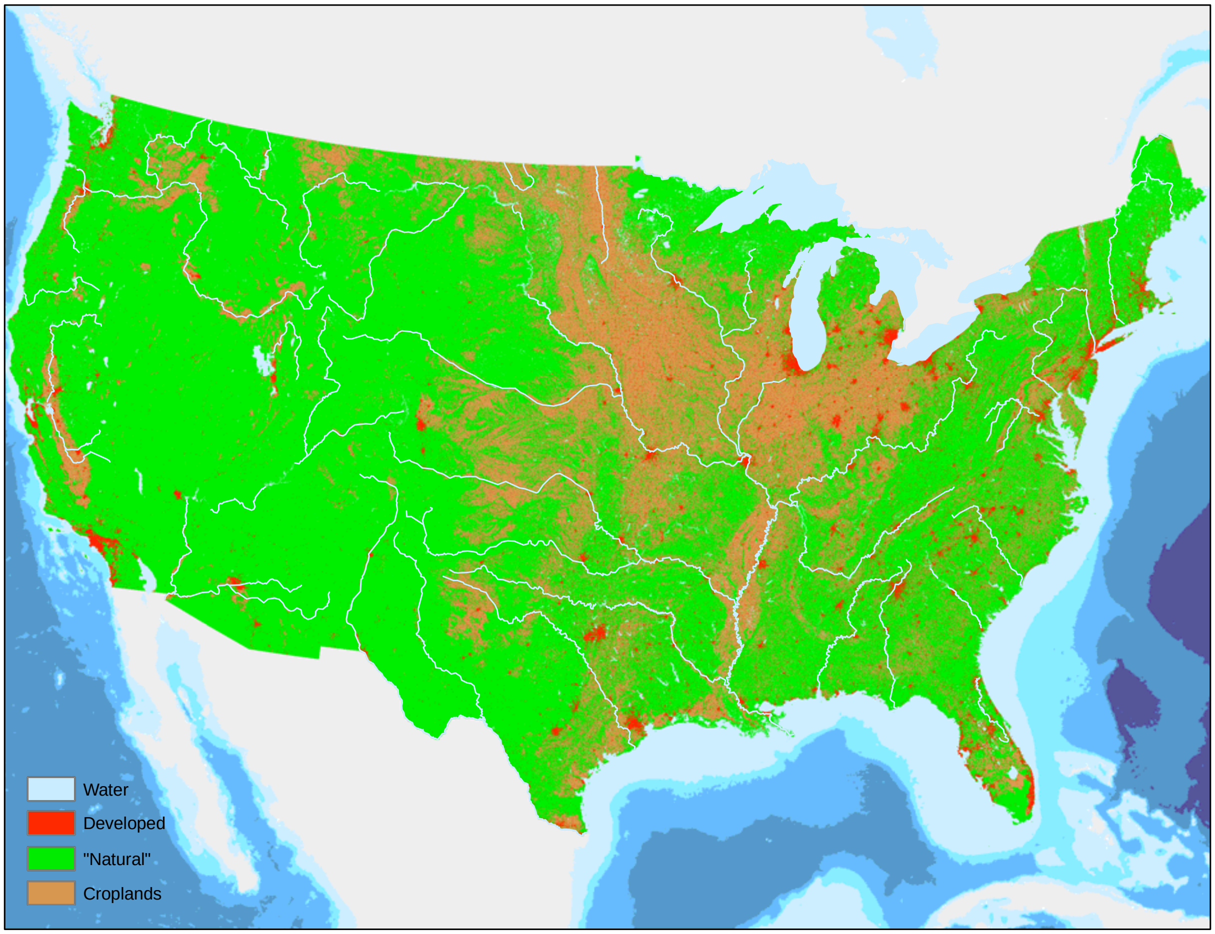

Figure 3: 2001 Land-cover map for conterminous U.S. Those categories shown in Figure 2 have been condensed into three main categories: “natural,” cropland, and developed. Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

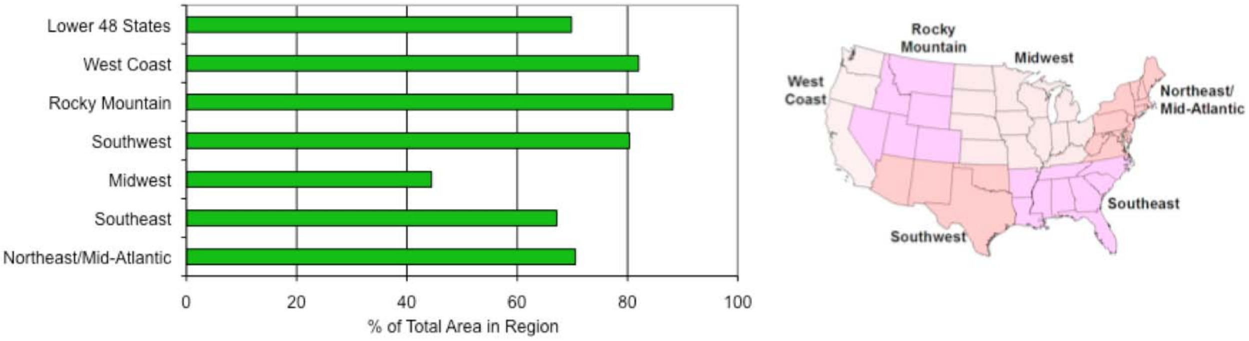

Figure 4: The percent of total area in each region (and the lower 48 states as a whole) that is classified as “natural” land cover (see text for definition). Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

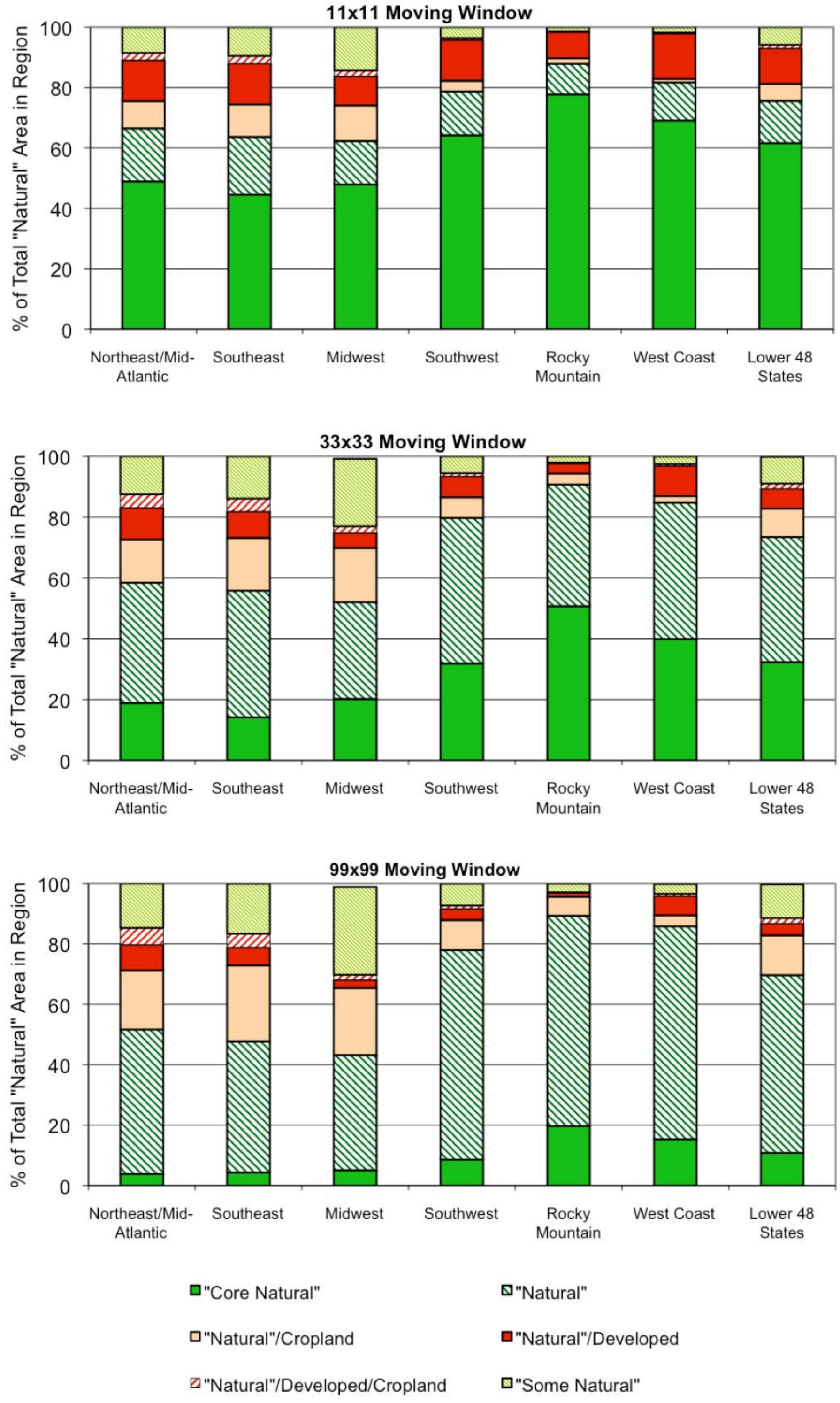

Figure 5: Regional and national (lower 48 states) results for the pattern of "natural" landscapes. Data are presented as the percentage of total "natural" area in the region. The impact of the size of the "moving window" analysis tool (see text) can be seen by comparing the three panels. An 11x11 window contains 121 30-m pixels, which is equal to 26.9 acres (10.9 ha); a 33x33 window is 242 acres (98 ha); a 99x99 window is 2224 acres (900 ha). See Table 5 for explanation of legend. Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

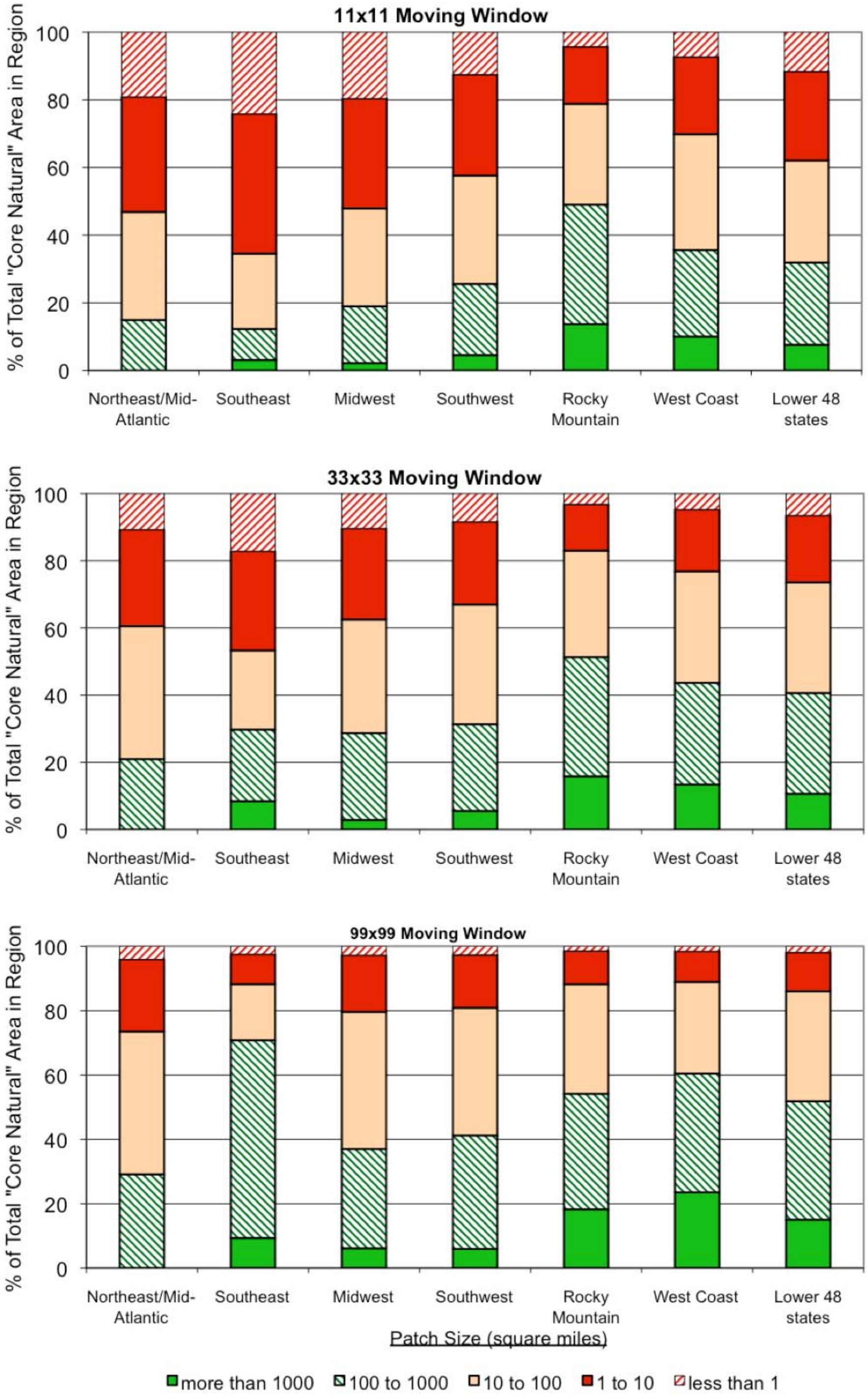

Figure 6: Patch size of "core natural" pixels, regionally and nationally (lower 48 states). Data are reported as a percentage of all "core natural" in a given region for several different patch size categories. Note that there is considerably more "core natural" area found using an 11x11 window (see Figure 5); thus these two figures should be evaluated together. Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

It is important to reiterate that the patch sizes reported in Figure 6 do not include the width of the buffer zone that is created by the analysis (i.e., in order to be considered a “core natural” pixel, a “natural” pixel has to be bordered by other “natural” pixels extending about one-half the width of the moving window).

What Do the Data Show? Based on 2001 data for the lower 48 states, about 70% of the land cover can be classified as “natural” land cover; this percentage ranged from about 45% in the Midwest to 88% in the Rocky Mountain region (see Figure 4). The analysis for this indicator involved placing square analysis tools (moving windows) around each “natural” pixel, a process that yielded pattern descriptions for each “natural” pixel for each of the three moving window sizes (see Figure 5). Finally, those patches of “core natural” land cover were grouped together and the size of these patches was reported (see Figure 6).

For analysis using the 33x33 moving window:

- Twenty-three percent of the total area was “core natural” based on the composition of its surroundings (see definitions). Regionally, the percent of “core national” lands was higher in Western regions and overall ranged from a high of 45% in the Rocky Mountain region to 9% in the Midwest region.
- Thirty percent of the total area had a “natural” landscape pattern dominated by “natural” lands with some croplands and/or developed lands mixed in. Regional patterns were similar to that for “core natural.”
- About 7% of the total area had a “natural”/cropland landscape pattern that includes some cropland and minimal amounts of developed lands. This pattern was evident in 8-12% of the Eastern and Midwest regions, while less than 2% of lands in the West Coast region had this landscape pattern.
- About 5% of the total area had a “natural”/development pattern. For most regions, 5–8% of land area had this pattern. The Rocky Mountain and Midwest regions had only 2–3% of their area with this pattern.
- Very little of the total area (about 1%) had what can be called the “some natural” landscape pattern.
- “Core natural” parcels were most often (one-third of the time) found in patches ranging from of 10 to–100 square miles in size; 11% of “core natural” parcels were in patches of at least 1000 square miles in size.
- The Rocky Mountain region had the highest proportion (16%) of “core natural” in patches larger than 1000 square miles and the lowest proportion (about 50%) in patches smaller than 100 square miles.
- The Northeast/Mid-Atlantic region had the highest proportion (about 80%) of “core natural” in patches smaller than 100 square miles and no patches larger than 1000 square miles.

For analyses using the 11x11 and 99x99 moving windows:

- In general, compared to the 33x33 moving window[7], the 11x11 moving window yielded proportionally more “core natural” land area, and the 99x99 yielded proportionally less (see Figure 5).

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[7] The 33x33 window (~1 square km) was used for the analyses reported in the *2008 State of the Nation’s Ecosystems* report.

In general, the proportion of “core natural” land cover in different patch sizes was similar across all three moving window sizes (see **Figure 6**). However, this similarity in results masks the fact that increasingly more of the landscape fell into the category of “core natural” moving from the largest (99x99) to the smallest (11x11) moving window (see Figure 4).

While data are available from the 2001 NLCD (see Box 2 for a description of the NLCD product), it is a non-trivial matter to evaluate changes between two time points on a pixel-by-pixel basis (see Box 4) and time was not available for such a comparison for this report.

Box 4—Estimating Change Over Time in the Indicators. The indicators described in this report will be much more meaningful when two or more time points of data are presented. The main source of land-cover data used in this report is the National Land Cover Dataset (NLCD; see Box 2), for which nationwide data are now available for 1992 and 2001. It is an extremely challenging proposition to compare pixel-level changes from 1992 to 2001. For example, slight misalignment of pixels between the two time points would yield apparent changes in land cover where there may actually have been none. Several data products are now included with the 2001 NLCD, including one that might be ideal for assessing pixel-level changes. At the time of the analyses for this report, it was not possible to compare the 1992 and 2001 data.

How Are Roads Incorporated In the Pattern Analyses? The Task Group took a strong interest in an indicator of road density (see Box 5), however the project’s goal of identifying a small number of indicators and the fact that this indicator does incorporate roads (as “non-natural” landscape elements) led the Task Group to eliminate the road density indicator from its final recommendations (however, see Appendix B)
.

Box 5—Why Does the Task Group Care About Road Density?
The prime reason supporting a road density indicator is that roads directly influence the accessibility of areas to humans; very low road density in an area implies a higher degree of refuge. Secondary reasons deal with chemical and physical impacts, especially in a freshwater context (e.g., increased sedimentation); even the smallest roads have been found to have significant impacts. The other main reason roads are important is because they have the potential to create partial or complete barriers to animal movement.

Farmlands Indicator: Proximity of Cropland to Residences

There was an indicator in the 2002 *State of the Nation's Ecosystems* report that addressed the tension between agriculture and expanding development (Fragmentation of Farmland Landscapes by Development). The Task Group felt that the previous indicator was unnecessarily complex, and a new indicator is recommended that has been crafted in the spirit of the indicator from the 2002 Report.

What Is the Task Group Recommendation? The Task Group recommends an indicator that measures the amount of cropland at varying distances away from residential dwellings. The amount of cropland found within distance ranges (e.g., 100 feet, 100 to 300 feet, etc.) of a house will be reported.

In contrast to simply reporting the number of homes within a given area, this indicator provides explicit information on the spatial pattern of residences in relation to cropland. For example, the indicator will distinguish between the effects of the same number of houses clumped together versus spread out more evenly across an agricultural landscape.

Due to data limitations, spatial locations of individual households are available only for a few areas across the country. The Task Group's preliminary recommendation was to utilize land-cover data to identify human development across the landscape in lieu of more detailed data on household locations. However, reviewer feedback from an earlier draft of this report indicated that land-cover data are simply too coarse and would miss many single family dwellings, which are of key interest for this indicator. Thus, the 2008 State of the Nation's Ecosystems report includes this indicator as a placeholder given that national-level data are not available on the location of individual households.

The Task Group has a keen interest in making the indicator sensitive to the intensity of agricultural operations by reporting the proximity of different types of agricultural operations (e.g., row crops, vegetable farms, confined animal feeding operations, etc.) to development. Data to enable this reporting are not currently available nationwide.

How Does the Recommendation Differ from the Indicator in the 2002 Report? The indicator in the 2002 Report relied on a moving window analysis (see Box 3) to describe the spatial pattern of cropland and development—based strictly on land-cover data. Like the new indicator, the previous indicator would have distinguished between areas with clumps of development versus an even distribution of development across the landscape (see Appendix C); however the data would have been reported quite differently. Specifically, an area would have been classified as having low, medium, or high fragmentation by development. The current recommendation is more specific for two reasons. The location of households will be used (although see the discussion below on their limited availability), and actual distances between croplands and development will be reported.

Why Do We Care About This Indicator? Farmland ecosystems, which have been created by humans, are ironically under increasing threat from human development. This often leads to the permanent removal of high quality farmland from production. Housing and other development in farmland areas may compromise the economic viability of farming, causing *disincentives for continued farming* (e.g., high land values that encourage farmers to sell). Beyond basic issues such as fertility, water availability, etc., the food production capacity of agricultural land is a function of the ability to use farming practices without creating *spillover effects* that might harm or annoy people who live nearby (e.g., noise, dust, chemical overspray). See Appendix C for more details. The result can be the elimination of agriculture in an area, or its restriction to smaller parcels (note that specific types of agriculture such as vegetable farms may be able to flourish in such a fragmented farmland landscape because of the proximity of customers to their fields, although such "pick-your-own" or farmstand opportunities are limited).

What Are the Details of the Indicator Design? As with several other indicators in this report, the starting point will be a land-cover map composed of a grid of pixels (see Box 2); housing data would then be superimposed on the land-cover map. The indicator will be implemented by determining the distance from the center of a cropland pixel to the center of a pixel that contains the nearest household (Figure 7). The assumption is that farming of cropland within any given distance range (e.g., 100 to 300 ft.) might lead to spillover effects capable of traveling this distance and affecting residential dwellers. Data will be reported as the amount of cropland within various distance ranges from the nearest house.

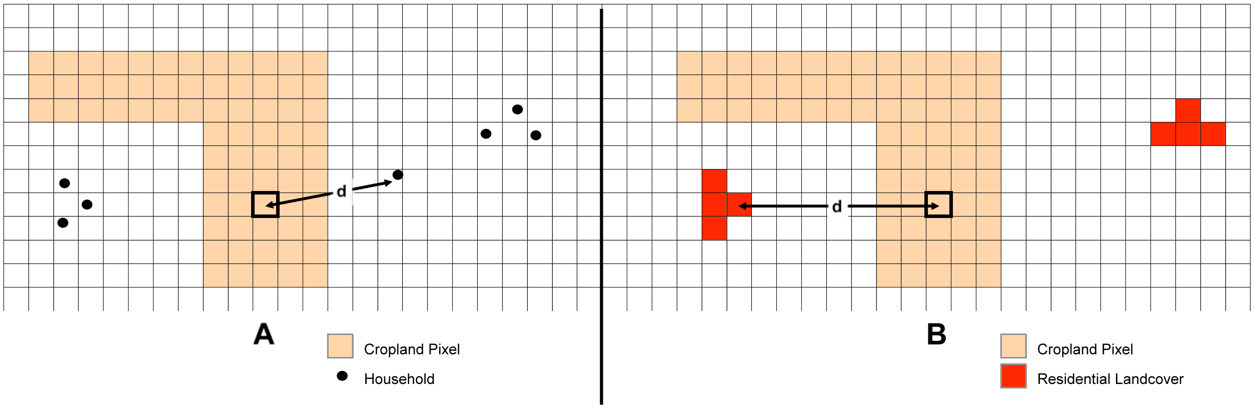

Figure 7: Schematic showing two methods for calculating the recommended indicator of proximity of croplands to residences. (A) Sample farmland landscape with cropland shown as tan square pixels and several households shown (black dots). The distance to the nearest house (d) is shown for the cropland pixel outlined with a heavy black line; this distance is computed from the center of the cropland pixel to the center of the pixel within which the household point datum falls. (B) Alternative method to panel A relying on land-cover data as a proxy for households. The distance to the nearest pixel classified as residential land cover (d) is shown. Note that land cover is only a proxy for actual households, which is emphasized in this sketch because the isolated house shown in panel A is not captured in the land-cover data shown in panel B. Hence, using land-cover data as a proxy for actual household locations, the distances determined will, in general, be somewhat larger.

How Would the Indicator Data Be Presented? Data on individual household locations are currently only available on a limited basis. Analyses were conducted for the only two locations for which spatial databases were identified (the entire state of Maryland and Hunterdon County, NJ). Land-cover data are for 2001[8] and 2002 for Hunterdon County and Maryland, respectively (see Appendix C). Results from the analysis described above are shown in Figure 8. Examples of conclusions that could be drawn from these data are shown in Box 6.

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[8] Note that preliminary data from the 2001 NLCD were used for this analysis.

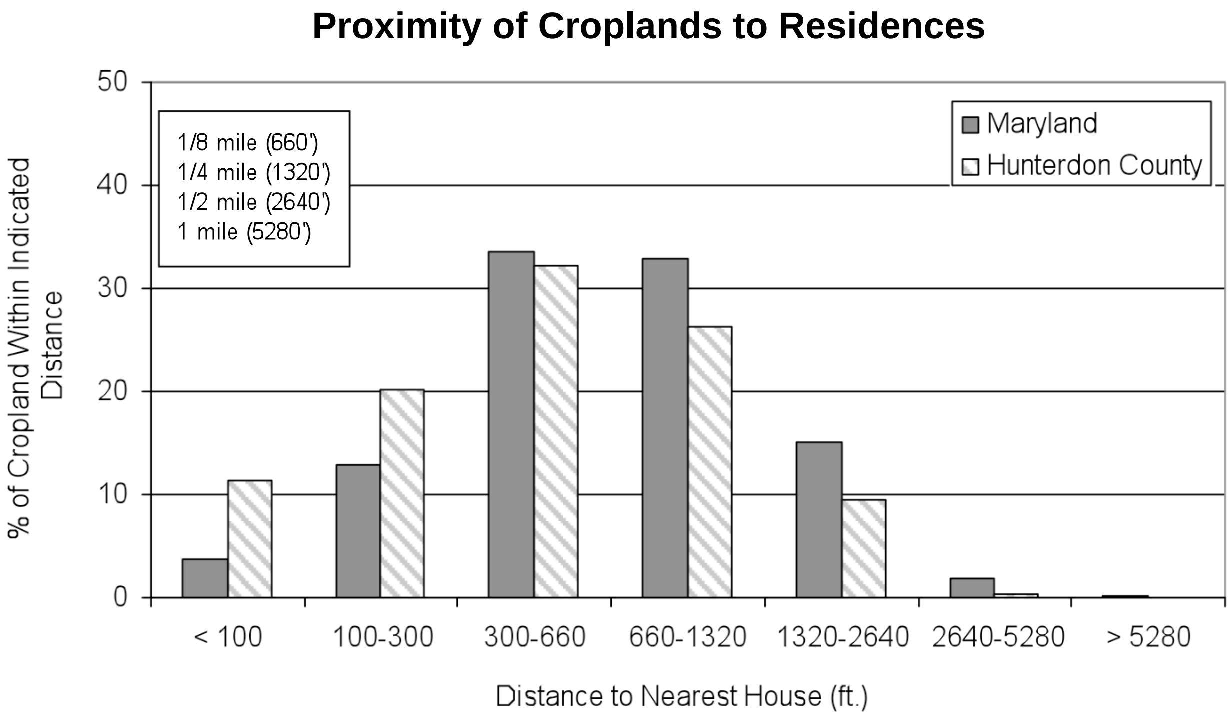

Figure 8: Preliminary results on the proximity of cropland to residences for Hunterdon County, NJ (data courtesy of Rick Lathrop) and Maryland (data provided by USEPA, although originally from Maryland Department of State Planning). Note that x-axis distances are approximate. Analyses provided by analysts with the US EPA and US Forest Service.

Box 6—Stories We Could Tell About the Proximity of Cropland to Residences.

The following are examples of stories that could be told from the sample data presented in Figure 8.

- Proportionally, more than twice as much farmland is within 100 feet of a house in Hunterdon County than in Maryland.
- The majority of cropland is within 1/4 mile (1320 ft.) of a house in both study areas.
- Almost no cropland is over one-half mile (2640 ft.) from a house in either study area.

It will be necessary to simplify the data presentation shown in Figure 8 in order to report data for multiple time points. It is recommended that three distance classes (e.g., <100 ft., 100 to 1320 ft., and >1320 ft.) be selected for graphs of time trends.

The data would also be presented in map form. The most straightforward way to do this would be to map only cropland for the most recent year of data, with pixels of cropland color-coded based on their distance from the nearest house (see Figure 9 and Figure 10). This would mirror the presentation in Figure 8.

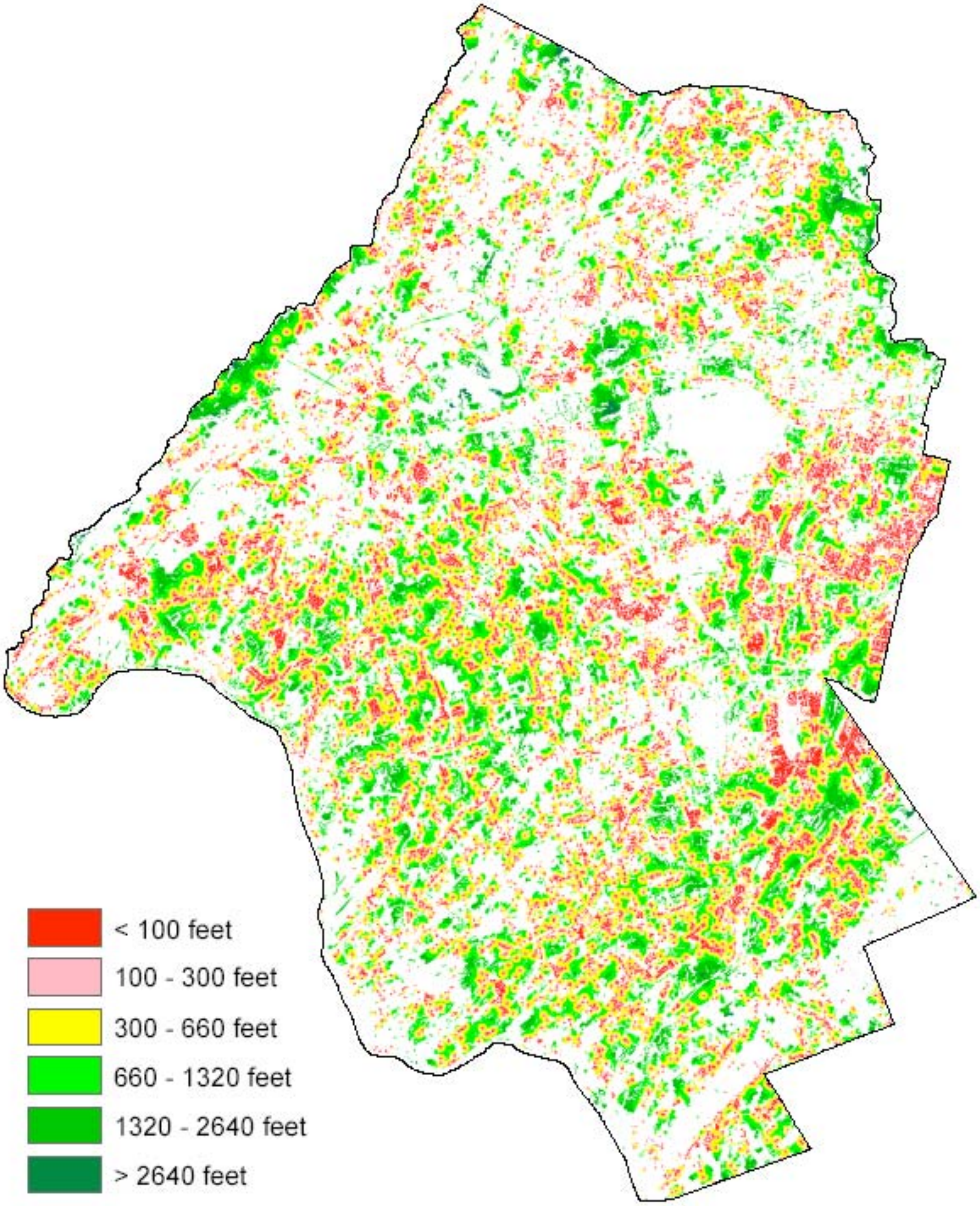

Figure 9: Map of proximity of croplands to residences for Hunterdon County, NJ (see Figure 8). Every cropland pixel is colored based on its proximity to the nearest house. Data courtesy of Rick Lathrop, and data analyses provided by analysts with the US EPA and US Forest Service.

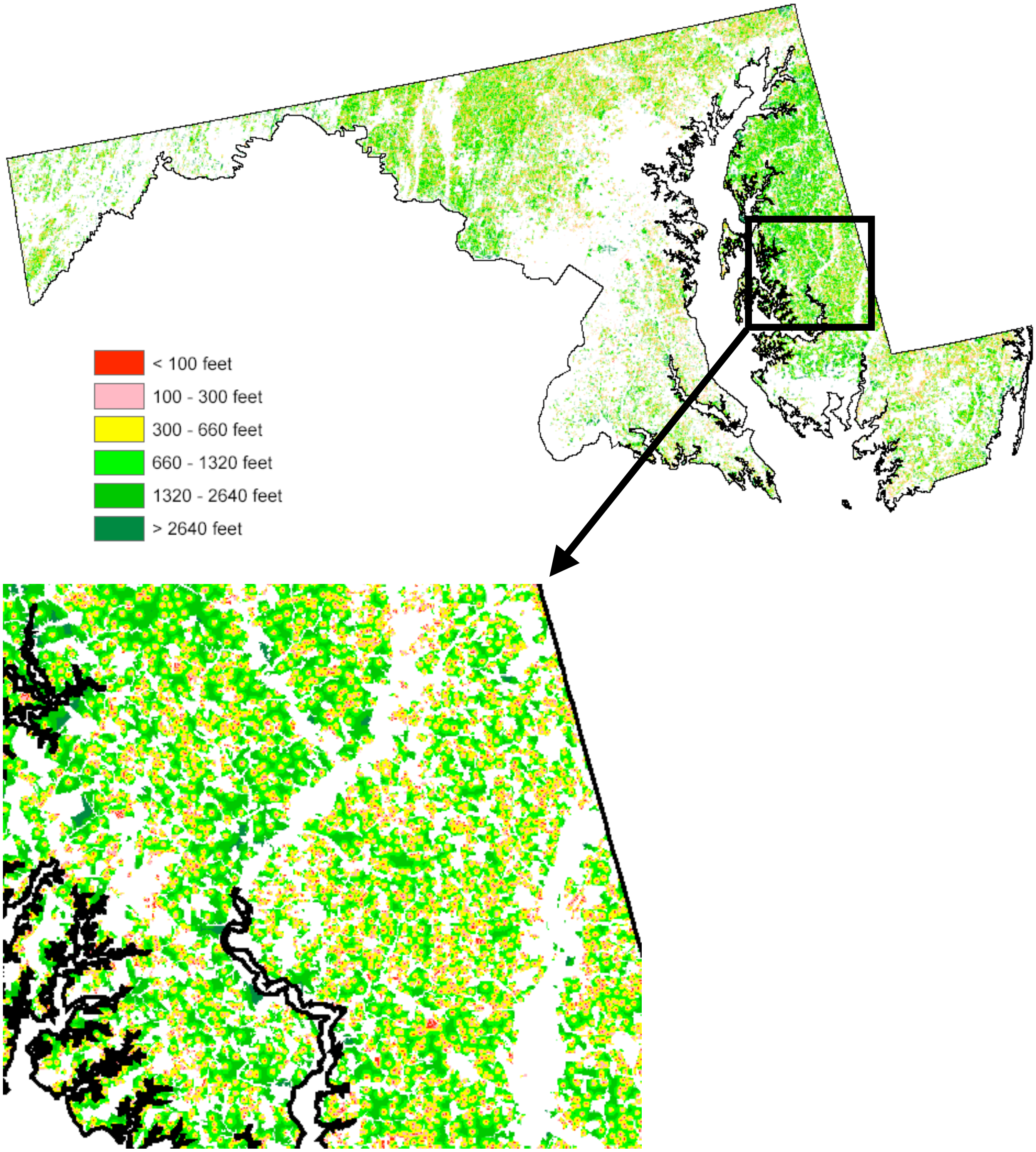

Figure 10: Map of proximity of croplands to residences for the state of Maryland (see Figure 8), with an area on the eastern shore of the Chesapeake Bay shown in detail. Every cropland pixel is colored based on its proximity to the nearest house. Data analyses provided by analysts with the US EPA and US Forest Service.

What Is the Difference Between Using Land-Cover and Housing Location Data?

Unfortunately, a nationwide database on the location of households is not available. The Task Group's preliminary recommendation had been to use land-cover data, thereby relying on pixels that have been classified as residential development[9] on land-cover maps as proxies for individual residences (Figure 7B). It is understood that land-cover data will not capture low-density housing very well, because isolated homes—or even small collections of homes next to farm fields—will most likely not be classified as residential development in satellite-derived land-cover data. Indeed, the differences are significant, as can be seen in the comparisons for Hunterdon County, NJ (Figure 11) and for the state of Maryland (Figure 12). In both cases, analyses using the actual housing location data show that croplands are closer to residences than when land-cover data are used. A new map for Hunterdon County, NJ, which uses land cover as a proxy for household locations, is shown in Figure 13.

It would appear that general conclusions one might draw are similar regardless of whether land-cover data for more precise household location data are used. However, a more extensive comparison would undoubtedly highlight the superiority of data on household locations for describing the pattern of development in and around our nation's farmlands. This indicator is included in the 2008 State of the Nation's Ecosystems report as a "data gap" based on feedback from the review process suggesting that it would be far more valuable to evaluate this indicator using data on the spatial location of houses across the country.

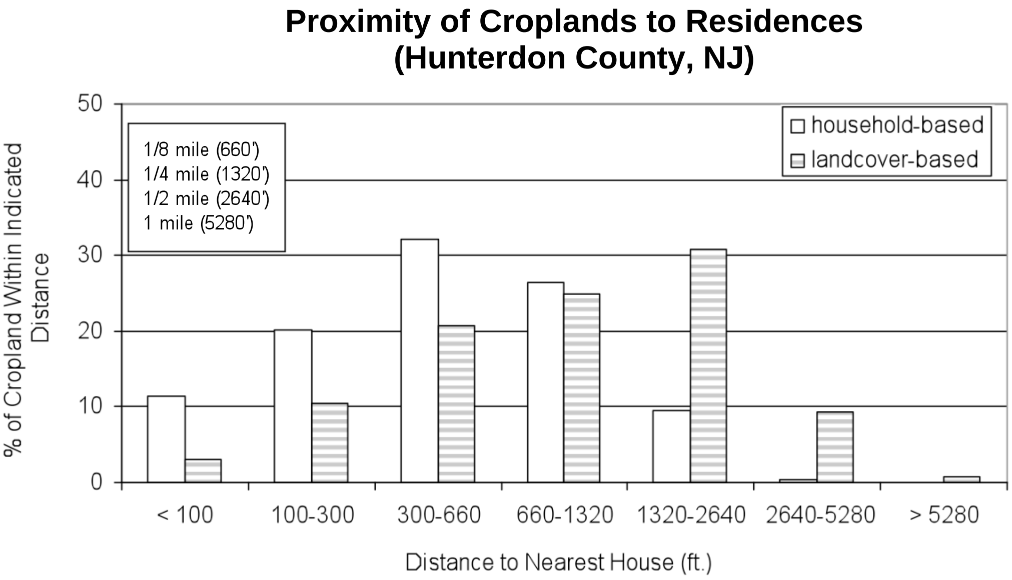

Figure 11: Comparison between using land-cover data versus actual housing locations to determine the proximity of cropland to residences for Hunterdon County, NJ (data courtesy of Rick Lathrop). Note that x-axis distances are approximate. Data analyses provided by analysts with the US EPA and US Forest Service.

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[9] Typical land cover data include classifications for different types of development, such as one or more classes of residential, commercial, and transportation. Landcover data are recommended here as a proxy for houses, so only the residential classes would be used.

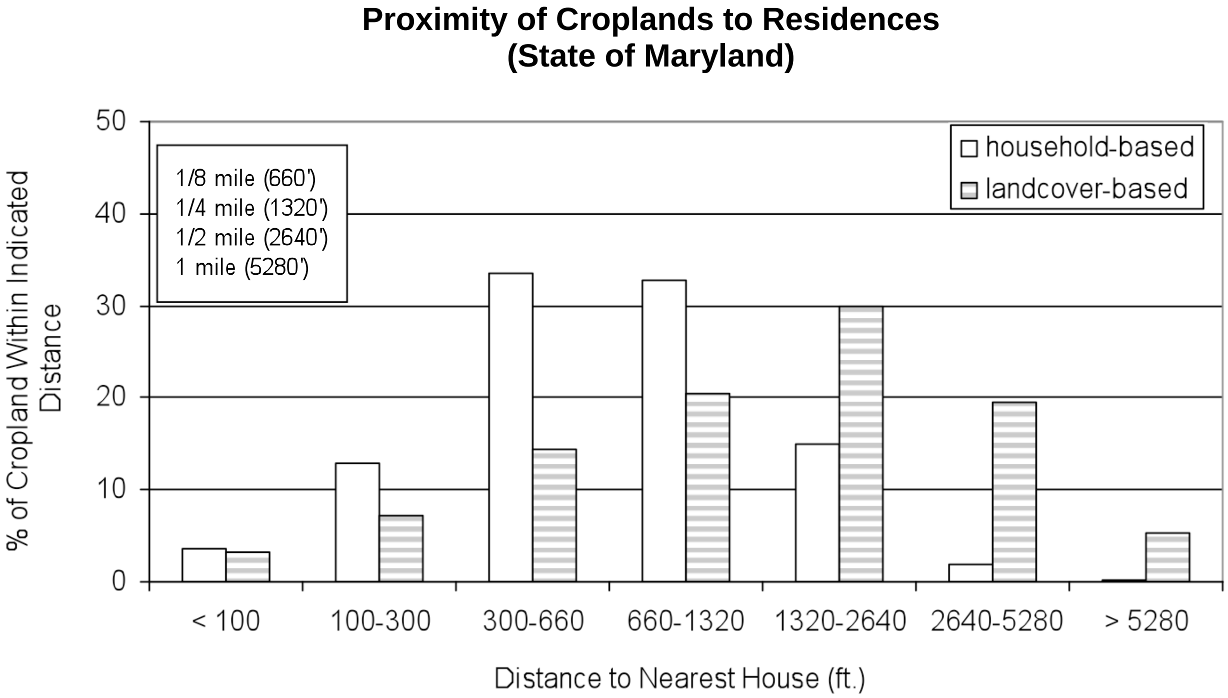

Figure 12: Comparison between using land-cover data versus actual housing locations to determine the proximity of cropland to residences for the state of Maryland (data provided by US-EPA, although originally from Maryland Department of State Planning). Note that x-axis distances are approximate. Data analyses provided by analysts with the US EPA and US Forest Service.

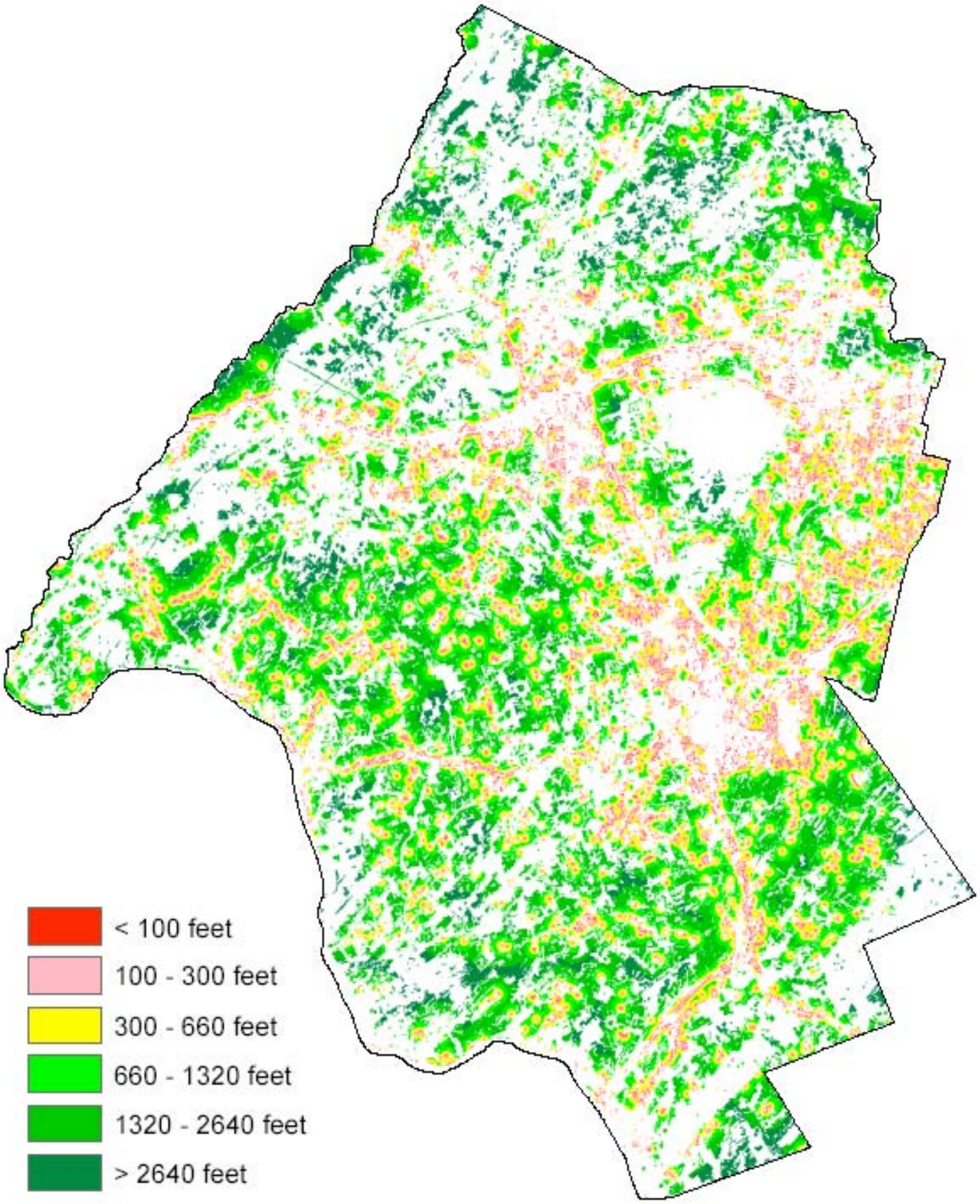

Figure 13: Map of proximity of croplands to residential land cover for Hunterdon County, NJ. Indicator is computed as the distance from a cropland pixel to pixels that have been classified as residential (see text; compare to Figure 9). Every cropland pixel is colored based on its proximity to the nearest residential pixel. Data courtesy of Rick Lathrop, and data analyses provided by analysts with the US EPA and US Forest Service.

Pattern of Forest Landscapes

There were two main criticisms of the *Forest Pattern and Fragmentation* indicator from the 2002 *State of the Nation's Ecosystems* report. It was perceived that the indicator was not adequately sensitive to "natural heterogeneity" in the West and that it was not sensitive to roads and other human development. In addition, the presentation of the indicator was difficult for a general audience to understand. All three of these issues are addressed with the Task Group's recommendations discussed below.

What Is the Task Group Recommendation? The Task Group recommends an indicator that will describe the *structural* patterns of semi-natural and "natural" forests. Specifically, the indicator describes the size of patches of "core forest" land cover, both regionally and nationally. "Core forest" is defined as small parcels (~1/4 acre), or pixels, of forest land cover surrounded by a specific amount of forest and other "natural" land cover (grasslands, shrublands, wetlands, other fresh waters, and coastal waters).

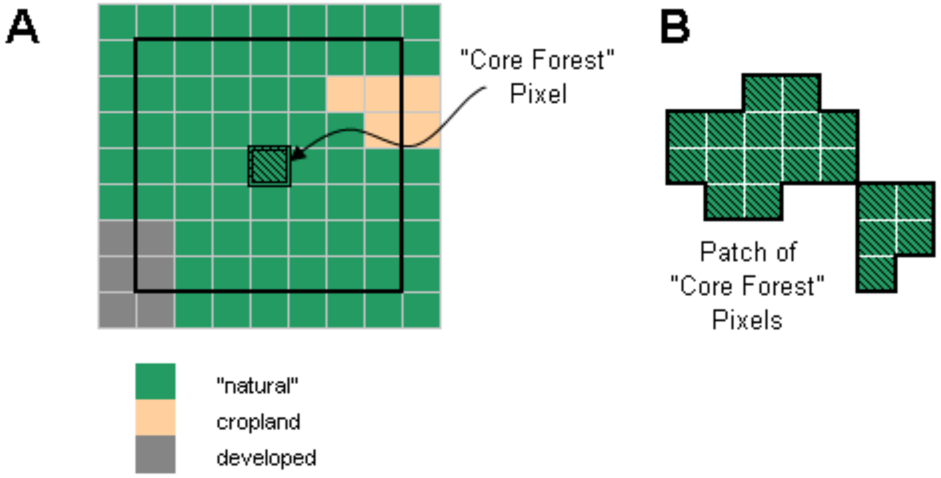

Figure 14: (A) Schematic of how "core forest" pixels are determined from a typical land-cover map. The density of "natural" pixels found within a moving window (see Box 3) of a particular size—here a 7x7 moving window is shown. If the density of "natural" pixels exceeds the required threshold (e.g., at least 90% "natural") then the pixel at the center of the moving window is classified as "core forest". (B) The second step of the analysis for this indicator is to join together all pixels of "core forest" and report the size of the resulting patches.

In general terms, as more non-forest cover is present in a given area, it becomes more difficult for a forest-dependent organism to make its way across that area. While some interior species require unbroken expanses of forest, the indicator is based on the assumption that other "natural" lands intermingled with forest do not appreciably lower connectivity experienced by forest species in general (see background section, p. 16). This modification to the indicator should make the indicator much more sensitive to natural heterogeneity in the West.

The recommended indicator is based on a second assumption that the presence of roads on a forest landscape is an important structural pattern that most likely has ecological implications (see background section, p. 16).

Why Do We Care About This Indicator? The degree to which croplands and development are interspersed with semi-natural and "natural" forest land cover has a direct impact on the *structural* pattern of forest landscapes. This process, for example, can lead to these "natural" lands being broken into smaller, more isolated landscape units.

Assessments of the structural properties of landscapes are inherently limited in their capacity to describe ecological functioning. Deciding whether or not a particular forest landscape supports good ecological functioning is complex and will vary by species. A bear may not hesitate to traverse a narrow farm field to access a neighboring forest, whereas a particular type of forest-interior bird may simply avoid flying across such a break in the tree canopy. Functional connectivity and other aspects of how landscapes function ecologically are difficult to generalize and continue to be an active research focus of many landscape ecologists. That said, the size of patches of "core forest" provides general information about the degree to which cropland and development either encroach upon or are intermingled with these "natural" areas.

What Are the Details of the Indicator Design? As with several other indicators in this report, the starting point will be a land-cover map composed of a grid of "pixels" (see Box 2), and a "moving window" approach (see Box 3) will be used for the analysis. The recommendation is to evaluate the size of patches of "core forest." The underlying analysis is similar to that used in the 2002 *State of the Nation's Ecosystems*, with two major differences that are described at length below. Furthermore, the presentation of the data as patches of "core forest" is a departure from the approach used in the 2002 *State of the Nation's Ecosystems* report.

The general method used is to evaluate the density of different land-cover types (Figure 14) in a moving window analysis, ideally using windows of various sizes. Whether or not a particular pixel of forest land cover is considered "core forest" depends on what the density of "natural" pixels is in the moving window. Setting a density threshold is more-or-less arbitrary. That said, there is a body of work based on percolation theory (Stauffer and Aharony 1992) that is relevant in that it provides a way to describe the structural connectivity of landscapes without being constrained to an explicit set of processes governing the movement of organisms (see, e.g., Turner et al. 2003). Ideally, a range of density thresholds would be used in the analysis for this indicator, however, a single threshold (at least 90% "natural") was used here as well as for the *2008 State of the Nation's Ecosystems* report. It is worth noting that a separate indicator resulting from the Task Group process will focus on areas that are both 100% "natural" area and have a wide buffer of 100% "natural" pixels (see Pattern of "Natural" Landscapes, p. 20).

The first major difference between the Task Group's recommendation and the indicator from the 2002 *State of the Nation's Ecosystems* is that the density of all "natural" pixels—and not just forest pixels—within any given moving window will be evaluated. This resulted from a concern that, by assigning thresholds based solely on the density of forest pixels in a window, the indicator could not be used to distinguish between development (or cropland) interspersed with forest and shrubland (and other "natural" land-cover types) naturally interspersed with forest (i.e., "natural heterogeneity"). The 2002 Report's indicator attracted considerable criticism because of this.

As discussed briefly above, the second major difference between the Task Group's recommendation for this indicator and the indicator in the 2002 *State of the Nation's Ecosystems* is the recognition that roads (and railroads) are important landscape features that should be considered. For these analyses, all paved roads were incorporated into the land-cover map by changing the classification of any pixel to a "road" classification if a road cut across the pixel.

Then, those pixels carrying the “road” classification were considered as a type of development when determining the density of “natural” pixels during the moving window analysis. Railroads were not included, due to some lack of agreement on the appropriateness of doing so, but also due to a lack of data.

Note that there is a need to improve the characterization of low-density rural development, as well as the loss of habitat caused by the “footprint” of all roads in land-cover maps.

How Will the Indicator Data Be Presented? Data have been analyzed for the conterminous U.S., both for this report and for the *2008 State of the Nation’s Ecosystems* report (Heinz Center, 2008) by analysts with the USDA Forest Service and the U.S. Environmental Protection Agency. As describe above, the starting point was a land-cover map enhanced with data on the presence of roads on the landscape (Figure 2). A map of “core forest” pixels should be shown, with the underlying data also shown graphically, both regionally and nationally (Figure 15). The size of the moving window used in the analysis generally has a direct impact on the proportion of the total forest area that is classified as “core forest,” as can be seen by the difference in the height of the bars within regions in Figure 15. Just as with other indicators, like the *Pattern of “Natural” Lands* (p. 20), it would be ideal to have data available in map format via the internet in such a way that the user can dynamically create different permutations.

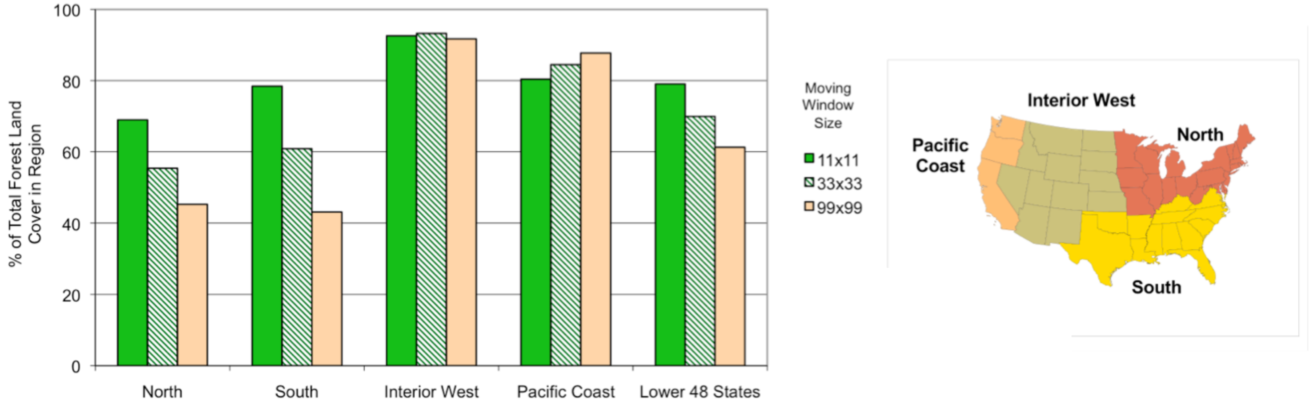

Figure 15: “Core Forest” Area, as a percentage of total forest land cover, regionally and nationally. The impact of the size of the “moving window” analysis tool (see text) can be seen by comparing the three panels. An 11x11 window contains 121 30-m pixels, which is equal to 26.9 acres (10.9 ha); a 33x33 window is 242 acres (98 ha); a 99x99 window is 2224 acres (900 ha). Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

The main component of this indicator would be to report on the proportion of “core forest” found in different size patches across the landscape. Results from the analysis for the conterminous U.S. are shown in Figure 16, also for three moving window sizes.

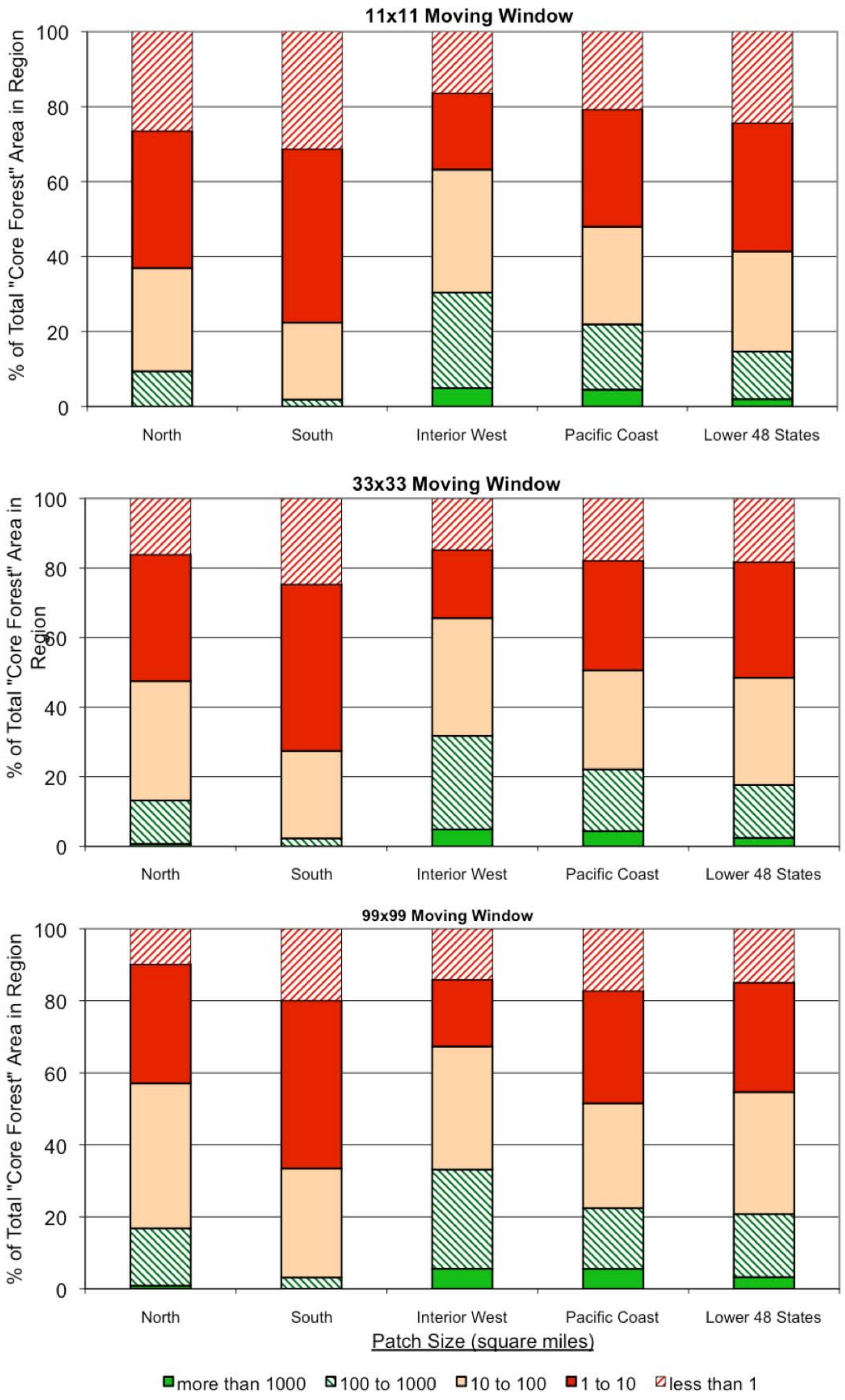

Figure 16: Patches of “core forest” as a percent of total “core forest” area, regionally and nationally. The impact of the size of the “moving window” analysis tool (see text) can be seen by comparing the three panels. An 11x11 window contains 121 30-m pixels, which is equal to 26.9 acres (10.9 ha); a 33x33 window is 242 acres (98 ha); a 99x99 window is 2224 acres (900 ha). Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

What Do the Data Show? Nationally for 2001, about 60% to 80% of forest land cover was classified as “core forest,” with increasingly less proportional area resulting from the use of larger moving windows (Figure 15). Data for several regions follow the general pattern with less “core forest” area with increasing moving window size, however there is basically no pattern for the Interior West region and the opposite pattern for the Pacific Coast region. These regional differences suggest that “core forest” areas found in the Interior West and Pacific Coast regions are large, at least relative to the largest moving window size. This agrees with findings of the size of “core forest” patches (Figure 16), which are described at more length below (note that the data from the 33x33 moving window analysis are the ones included in the *2008 State of the Nation’s Ecosystems* report).

For analysis using the 33x33 moving window:

- For 2001, about the same amount of “core forest” was in patches ranging from 1 to 10 square miles (33%) as was in the 10–100 square mile category (31%). Eighteen percent of “core forest” was in patches of less than 1 square mile, about 15% was found in 100–1000 square mile patches, and just over 2% was found in the largest patches, of more than 1000 square miles.
- The Interior West region had the highest percentage of “core forest” in large patches (nearly 30% in patches 100 to 1000 square miles in size and 5% found in patches larger than 1000 square miles); the Pacific Coast had the next highest percentage of “core forest” in large patches.
- The South had the highest percentage of “core forest” in smaller patches (nearly three-quarters found in patches 10 square miles or less); the North and Pacific Coast regions each had about 50%, and the Interior West had about one-third of “core forest” in patches of 10 square miles or less.

For analysis using the 11x11 and 99x99 moving windows: With the noted exception above of the Pacific Coast and Interior West regions, typically the 11x11 moving window analysis resulted in a lower percentage of the larger patches whereas the 99x99 moving window analysis resulted in a somewhat higher percentage of the larger patches, compared to the 33x33 moving window size. The reason for this is most likely that, as the moving window size is increased, the analysis becomes less sensitive to small amounts of “non-natural” land cover. Thus, a 99x99 window may include just less than 10% “non-natural” with the central pixel carrying the “core forest” designation, whereas that same central pixel may not be included as “core forest” if most of the “non-natural” pixels are found in close proximity (i.e., an 11x11 moving window found more than 10% “non-natural” within it).

Freshwater: In-Stream Connectivity

There was no indicator dealing with landscape pattern issues in the Freshwater chapter of the 2002 *State of the Nation's Ecosystems*. The project's Design Committee specifically asked the Task Group to revisit this decision, a process that ultimately led to the recommendation presented below.

What Is the Task Group Recommendation? The Task Group recommends an indicator that evaluates how the presence of dams and diversions affect the structural connectivity of freshwater systems at two different scales. The indicator is evaluated using many non-overlapping "subwatersheds,"[10] which are small units (on the order of 1000 acres in size) used to map the landscape from a hydrographic perspective. At the local scale, the indicator carries a value of zero if a dam is present within a given subwatershed. Hence, the indicator will explicitly report the presence or absence of dams in subwatersheds across the American landscape. If non-zero at the local scale, the indicator value is equal to the distance from the subwatersheds's *pour point* to the nearest dam or diversion encountered downstream (a pour point is the most downstream point within a subwatershed). In cases where the natural terminus (e.g., lake or ocean) is reached before a dam or diversion is encountered, this distance will be reported and the occurrence will be highlighted.

Note that while diversions are nominally considered to be equal to dams in this indicator, minimum characteristics of a diversion will need to be defined in order for it to be within the purview of this indicator (e.g., a diversion causes zero flow events at some point during the year). Data are expected to be less readily available for diversions, and they have not been included in the analyses described here.

Why Do We Care About This Indicator? Dams are omnipresent in the freshwater landscape: national inventories catalog more than 76,000 dams that are above minimum thresholds (i.e., 6 feet or higher and impound at least 50 acre-feet of water, etc. (Heinz Center 2002a)). Dams can affect the connectivity of freshwater systems at different scales (please see detailed literature review in Appendix G).

At broad scales, dams can limit or eliminate the migration of species to the ocean, for example, or prevent migratory species from accessing habitat crucial to a particular life-history stage, such as spawning and juvenile rearing. Within river and lake systems, loss of connectivity is of great importance to far-ranging migratory species such as salmon, sturgeon, bull trout, eels and lampreys, many species of which are at increased risk of going extinct. Higher connectivity within a river system leads to the opportunity for biota to maintain a higher diversity of migratory behaviors, which has been linked—in fish and mussels—to higher probabilities of persistence of individual species and to greater species richness; this presumably holds true for other species as well. In addition, higher connectivity means that more tributary streams are connected to each other, presenting increased opportunities for dispersal, recolonization, and the

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[10] Watersheds are hydrologically connected elements the landscape, often described as "hydrologic units" and named using a hierarchical system of "hydrologic unit codes," or HUCs. In this report, "subwatersheds" are equated with 12-digit HUCs, which are the smallest HUCs mapped for most of the country. Often "HUC" is used as a noun synonymously with watershed.

metapopulation dynamics these can create, permitting broader occupation of historic species ranges, and likely contributing further to increased species persistence and diversity.

In cases where downstream dams are present, there is support in the literature (see Appendix G) suggesting that a minimum of approximately 250 miles (500 km) of unobstructed downstream flow is necessary to support viable populations of large-bodied, long-lived, wide ranging riverine species like sturgeon (specifically those without an obligate marine migratory life history). It is worth noting that loss of connectivity can be reduced to some extent by the construction of fish ladders and other means that allow fish to navigate past dams—this indicator does not take into account how these efforts might impact functional connectivity for aquatic species (see literature review, Appendix G).

Connectivity within a local area, or subwatershed, is important to sedentary or relatively short-ranging migratory aquatic species, such as inland cutthroat trout, other native fish species, mollusks, and invertebrates.

Finally, beyond hindering movements of aquatic biota, dams can have profound effects by creating large ecological discontinuities. For example, both upstream reservoirs and downstream reaches often are highly altered habitat which may be both detrimental to native biota and beneficial to non-natives. Dams often alter flow regimes (variability in timing, volume, temperature, nutrients and water chemistry), leading to significant impacts on ecosystem pattern and condition (see indicators of altered hydrology[11]).

It is important to note further that natural barriers also exist in many systems and that a given feature (natural or artificial) will often be a barrier to some species or life stages, but not others, and at certain times or flow conditions, but not others. The indicators presented here focus on loss of connectivity over and above any natural fragmentation of aquatic systems.

What Are the Details of the Indicator Design? The analysis for this indicator is a two-step process that will depend on merging data on stream networks, the location of dams and diversions, and the delineation of subwatersheds. This has been accomplished for several selected geographic areas for this report, however, the effort involved was considerable and achieving such a merged dataset for the country will require a substantial investment of resources beyond the scope of this project. Briefly, the digital maps of the stream network are of varying quality and detail across the country, and the available data for dams are frequently inaccurate (for more details, see chapter on discussion of data gaps).

Ideally, this topic would be captured using two separate indicators—one detailing the degree of connectivity within subwatersheds and one dealing with the connectivity of subwatersheds to the larger stream network. However, the Task Group was charged with selecting a single indicator, if at all possible. Thus, the recommended indicator is ultimately a blend of these distinct concepts, with an emphasis on the connection of subwatersheds to the larger stream network.

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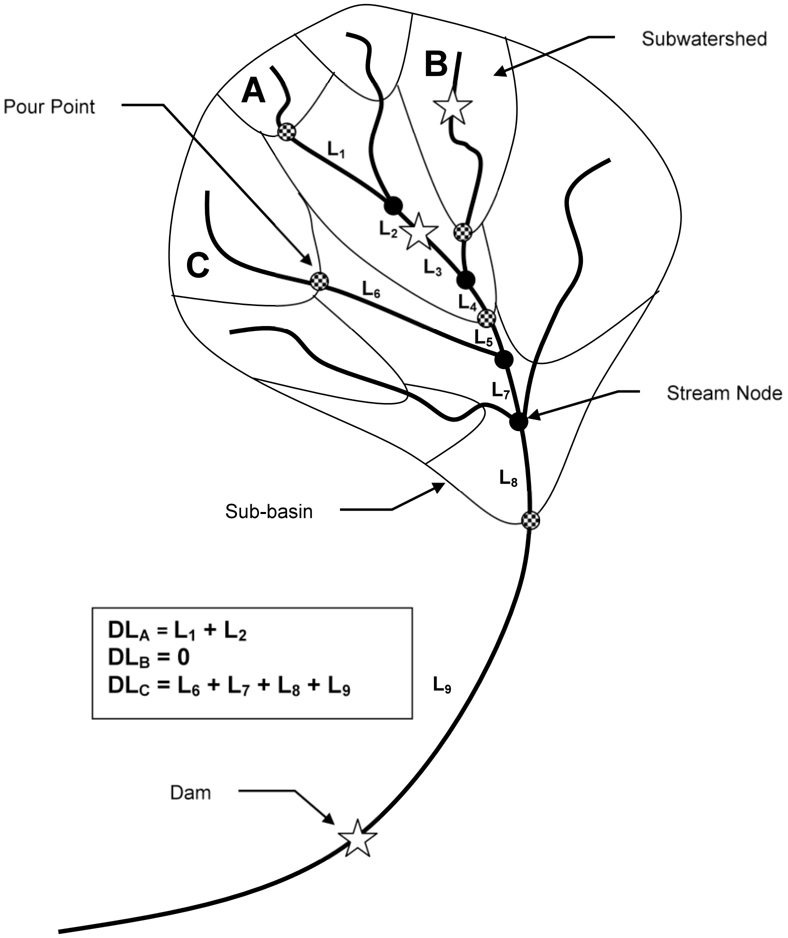
[11] The 2002 *State of the Nation's Ecosystems* had two indicators that dealt with altered stream flows, one in the Freshwater chapter and one in the Grassland-Shrubland chapter. The 2008 *State of the Nation's Ecosystems* has a core-national indicator on altered hydrology, plus the Grassland-Shrubland indicator that highlights conditions of zero flow.

As the first step in the analysis, the index is set to zero for a given subwatershed if there is a dam or diversion present within the subwatershed (see Figure 17). This is a considerable simplification of the separate indicator contemplated by the Task Group for connectivity within subwatersheds, which would range from 0 to 1 depending on the longest interconnected section of the stream network found in the subwatershed (see Appendix H for more details). The justification for this simplification is based on the assumption that connectivity downstream from a subwatershed is of secondary importance if the connectivity within the subwatershed is restricted due to the presence of a dam or diversion (see below for an analysis of the impact of this simplification). Note that this approach will, perhaps unfairly, assign a value of zero to the subwatershed even if the internal dam is very close to the headwaters within that subwatershed (i.e., very little of the internal network is affected).



$DL_A = L_1 + L_2$
$DL_B = 0$
$DL_C = L_6 + L_7 + L_8 + L_9$

Figure 17: Sketch describing how the freshwater connectivity indicator would be computed for a collection of subwatersheds within a sub-basin. Subwatershed pourpoints are shown as circles with hash marks, nodes in the stream network are shown as solid circles, and dams are shown as white stars; some pour points and segment lengths are omitted for clarity. For subwatershed A, the downstream length (DL) is simply the length from the subwatershed's pour point to the first node (L1) plus the distance from that node to the first downstream dam (L2). Subwatershed B would have an indicator value of zero because it has a dam within it. Subwatershed C would have the greatest indicator value (L6 + L7 + L8 + L9); note that there is no downstream dam located within the sub-basin. Note that stream node is used here simply to illustrate the computation of this index—it refers to a point where two or more stream segments join together.

Next, the distance along the stream network to the nearest downstream dam is determined (see Figure 17). This is measured from the "pour point" of the subwatershed, which is the furthest downstream point, or the exit point for all surface water within the subwatershed. Eventually, streams reach a natural terminus, be that the ocean, one of the Great Lakes, or evaporation in the desert. The special cases when a subwatershed has an unobstructed connection to the natural terminus of its stream will be highlighted in the data. It is important to distinguish between two subwatersheds, one of which has 100 miles of unobstructed flow to the ocean, whereas the other has 100 miles of unobstructed flow to a dam.

Note that it would be possible to measure the full unobstructed stream network—both upstream, downstream, and into tributaries—accessible to aquatic species. However, the simpler indicator that restricts distance measurements downstream along the main-stem of the river was thought to convey a similar message with considerably less analysis effort. When a concerted effort is undertaken to implement this indicator nation-wide, it would be wise to revisit the simplification given available resources, any improvements to the underlying datasets, and recent advances in analysis methods.

How Would the Indicator Data Be Presented? The necessary data were compiled for several sample areas across the country (Figure 18). These areas provide a range of stream network conditions, from largely dam-free to heavily dammed. In addition, a large number of subwatersheds were evaluated in one region (Upper and Lower Grande Ronde, Wallowa, and Powder sub-basins) in order to understand the behavior of the indicator across the region (Figure 19). The effort necessary to create an accurate geographic information system (GIS) with the available data far outweighed that needed to compute the indicator once the data were compiled (see Appendix I) for more details on the data and methods). All analyses were performed under contract by Gary Carnefix and supervised by Task Group member Chris Frissell; a report detailing the analysis is available from the Heinz Center by request.

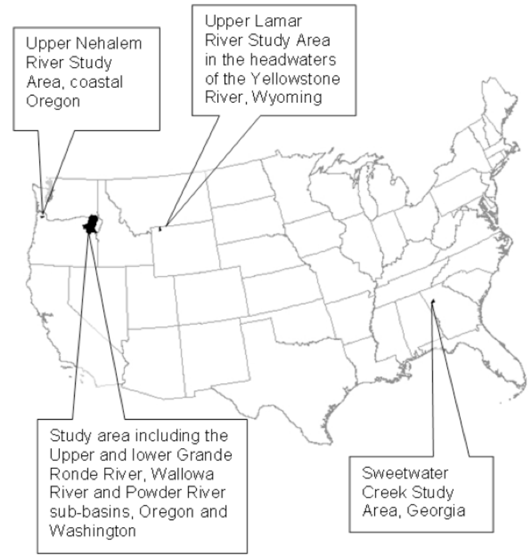


Figure 18: Study areas used for the indicator of freshwater connectivity. Note that the most extensive indicator work was done in the Grand Ronde-Wallowa-Powder study area.

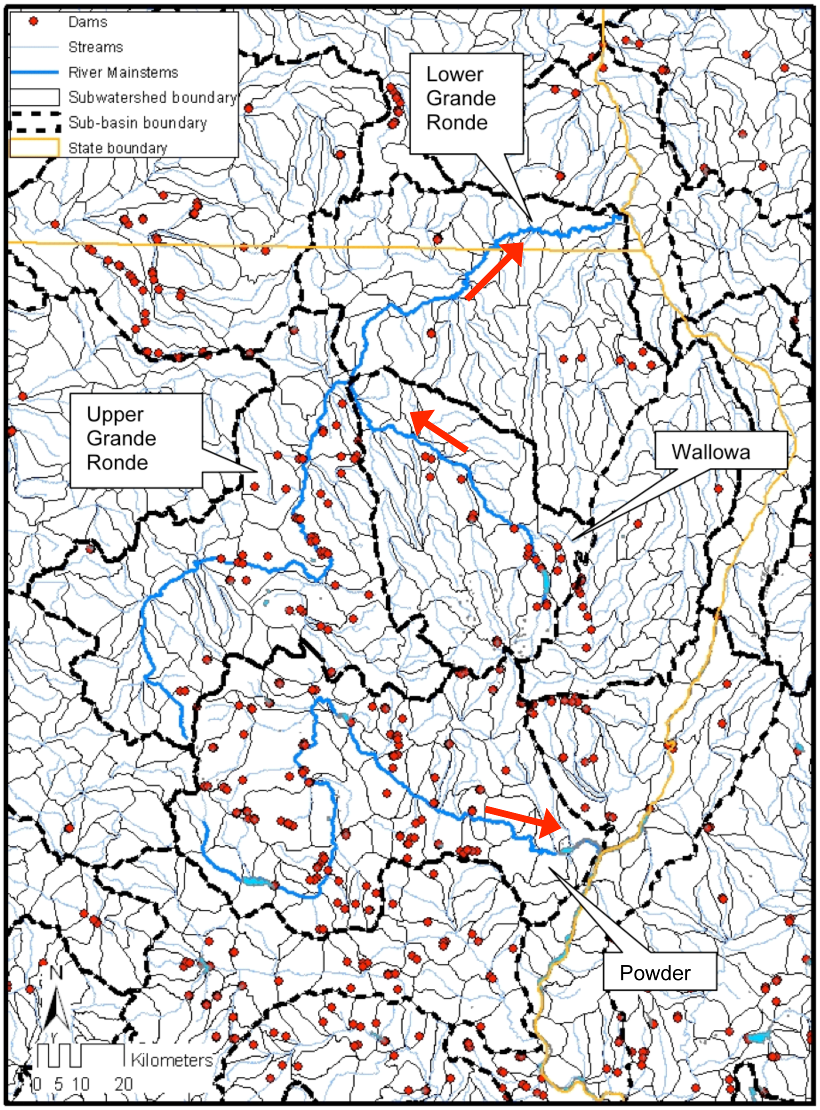


Figure 19: Reference map for Grande Ronde-Wallowa-Powder regional analysis, showing stream network hydrography, subwatershed (at a 12-digit HUC, or hydrologic unit code, resolution) and sub-basin (8-digit HUC) analysis unit and state boundaries, mainstem rivers and dam locations. Sub-basin names are shown (refer to text) as is the direction of flow (red arrows).

Results from these analyses are shown in Figure 20. The regional differences are substantial. The values determined for the Upper Lamar study area were the highest, and indicator values in the Upper Nehalem River study area were the lowest—however, one of these subwatersheds had full structural connection with the ocean (see asterisk in Figure 20). As full national coverage—not to mention multiple years of data—become available, multiple graphs and line graphs may be needed. The indicator values are conducive to being presented in map form, as shown in Figure 21. The Powder and Upper Grande Ronde sub-basins have the lowest indicator values whereas the Wallowa sub-basin has the highest indicator values. A map in a future edition of *The State of the Nation's Ecosystems* might not readily reveal differences at the scales shown in Figure 21, and it might be necessary to summarize the data by sub-basin, for example. See Box 7 for examples of the conclusions that could be drawn from these data.

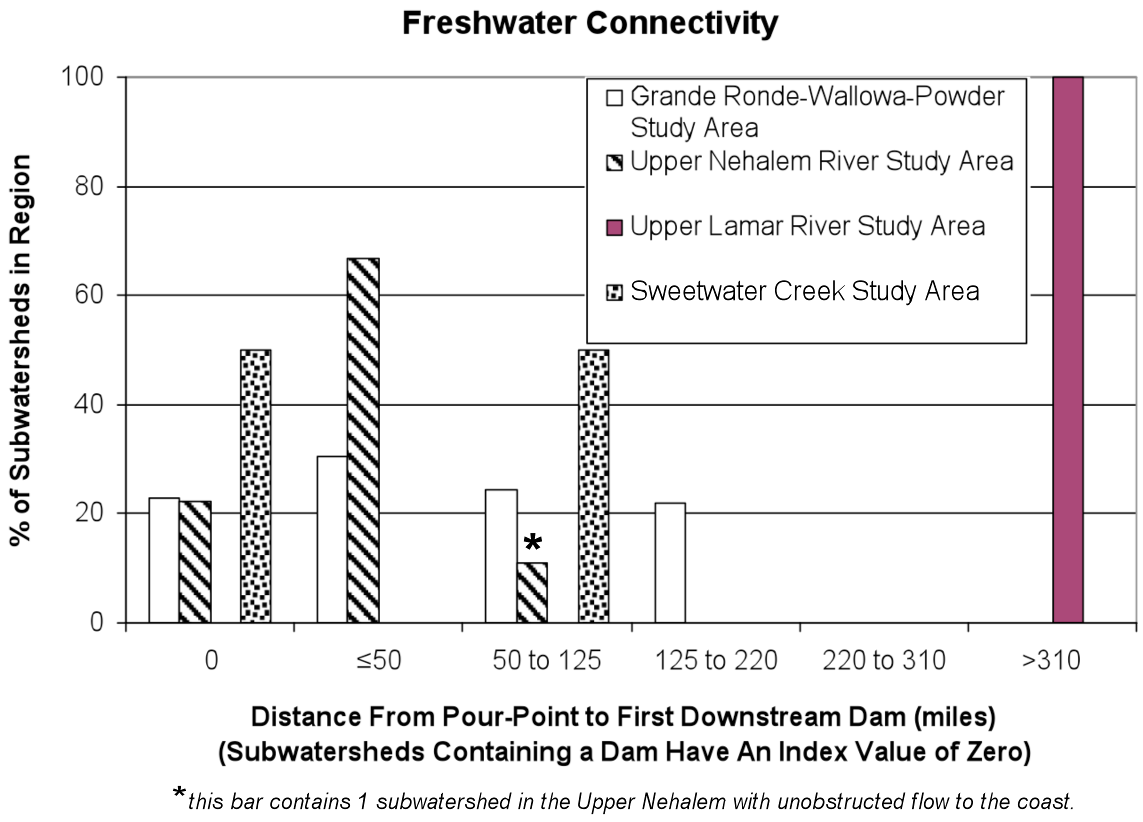


Figure 20: Indicator results determined for the regions shown in Figure 18. Indicator values determined by measuring the unobstructed distance along the river downstream of the pour point of subwatersheds; subwatersheds containing a dam have an index value of zero. Data analyses by Gary Carnefix.

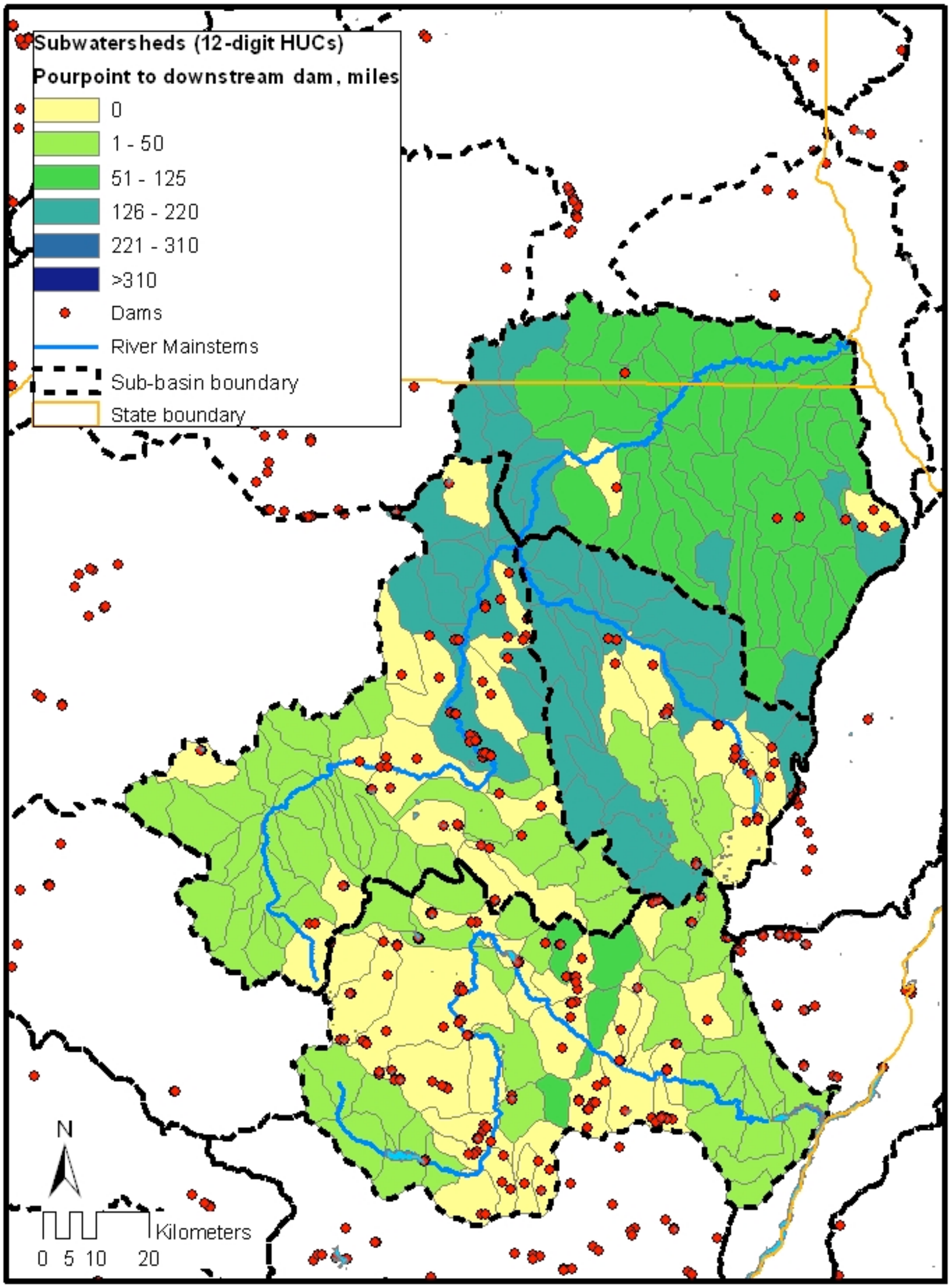


Figure 21: Indicator results for the Grande Ronde-Wallowa-Powder regional analysis: Upper and Lower Grande Ronde R., Wallowa R. and Powder R. sub-basins, Snake R. basin, Oregon and Washington. Subwatersheds are colored based on their index value (refer to Figure 19). Data analyses by Gary Carnefix.

The effect of the simplification discussed above (i.e., indicator is set to zero for subwatersheds that contain a dam) is shown in Figure 22. The y-axis shows the percent of subwatersheds that were downgraded to an indicator value of zero because a dam was found within the subwatershed. Only the Upper Lamar River watershed, which had no dams present, had no change to its indicator values. The most notable shift was for subwatersheds in the Sweetwater Creek study area, of which about 50% moved from the “50 to 125 mile” to the “0-mile” class because of the presence of one or more dams in them.

Note that a distinct feature of the presentation shown in Figure 20 and Figure 21 is that it provides clear accounting of the presence/absence of dams. That is, any subwatershed with an indicator value of zero has such because of the presence of a dam within the subwatershed, unless a dam is sited immediately downstream of the pour point of a subwatershed.

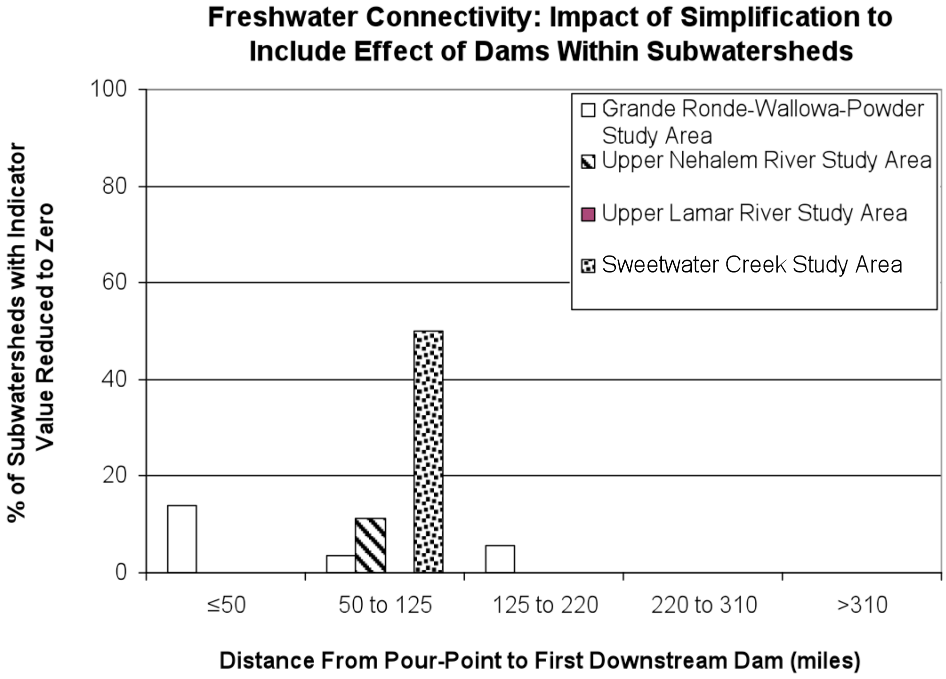


Figure 22: Analysis showing the effect of the simplification (i.e., indicator is set to zero for subwatersheds that contain a dam) discussed in the text. Those subwatersheds shown had their indicator value reduced to zero due to the presence of a dam within them. For example, about 50% of the subwatersheds in the Sweetwater Creek study area with the nearest dam 50 to 125 miles downstream carry an indicator value of zero, because they have a dam within them.

Box 7—Stories We Could Tell About Freshwater Connectivity.

The following are examples of stories that could be told from the sample data presented in Figure 20 and Figure 21.

- About 20% of subwatersheds in the Grande Ronde-Wallowa-Powder sub-basins and the Upper Nehalem River watershed have dams within them, compared to about half of the subwatersheds in the Sweetwater Creek watershed.
- All of the subwatersheds within the Upper Lamar River watershed were at least 310 miles upstream from the nearest dam.
- Of the 224 subwatersheds in all four study areas, only one was structurally connected to its natural terminus—the ocean.

Pattern of Grassland and Shrubland Landscapes

The 2002 *State of the Nation's Ecosystems* included an indicator of landscape pattern for the Grassland-Shrubland chapter, however data could not be processed in time for inclusion in the report. The indicator, *Area and Size of Grassland and Shrubland Patches*, distinguished between patches of grassland and patches of shrubland, and it included size categories from less than 10 acres to more than 10,000 acres. The Heinz Center viewed the 2002 Report's indicator as satisfactory and had taken preliminary steps toward initiating the data analyses required for the indicator. The Task Group's charge was broad and provided the opportunity to recommend revisions to (or replacements for) the existing Grassland-Shrubland indicator.

One of the Task Group's main goals was to increase the consistency between indicators across the various ecosystem chapters. The Task Group's recommendation presented below is an effort to improve consistency across indicators. Specifically, the new indicator will be essentially the same as the Forest indicator proposed by the Task Group. This same general approach was considered in replacing two other indicators from the 2002 Report that utilized patch-based approaches: *Shape of* "Natural" *Patches in the Farmland Landscape* and, in the Urban-Suburban chapter, *Patches of Forest, Grasslands/Shrublands, and Wetlands*.

What Is the Task Group Recommendation? The Task Group recommends an indicator—designed to be directly analogous to the Pattern of Forest Landscapes indicator (see page 38)—that will describe the *structural* patterns of semi-natural and natural grasslands and shrublands.

This indicator, like the Forest indicator, is based on two key assumptions. First, other "natural" lands intermingled with grassland or shrubland do not negatively impact ecological functioning (see background section, p. 16). This assumption implies that areas with a mixture of grassland, shrubland and other "natural" land cover are no less suitable for typical grassland/shrubland species than areas strictly covered with grassland or shrubland.

The recommended indicator is based on a second assumption that the presence of roads on a grassland-shrubland landscape is an important structural pattern that most likely has ecological implications (see background section, p. 16).

Why Do We Care About This Indicator? The degree to which croplands and development are interspersed with semi-natural and natural grasslands and shrublands has a direct impact on the *structural* pattern of these "natural" lands. This process, for example, can lead to these "natural" lands being broken into smaller, more isolated landscape units.

Patches of grasslands and shrublands are often naturally intermingled with each other and with forest or woodland. Each part of the country has a characteristic mix of small and large patches, and these intermingled patches provide the diversity of habitat types needed by the animals native to a region. (These patches are not static; they may shift over time, so that any single location may switch, for example, from grassland to shrubland, or from shrubland to forest, while maintaining the region's characteristic mix of land cover.) Activities such as fire suppression, grazing, agriculture, and residential, commercial, and industrial development can change this typical pattern, resulting in more or less of an area's grasslands or shrublands being found in large or small patches.

These alterations can create conditions that favor wildfires and affect wildlife populations. For example, fire suppression allows ponderosa pine to invade grasslands. The grassland plants are shaded out, and the grassland animals in the area are restricted to the smaller acreage of grasslands that remains. Non-native cheatgrass, for example, can expand into sagebrush (shrubland) following fire, thereby altering future susceptibility to fire and fire frequency patterns and reducing habitat for shrubland species.

Assessments of structural patterns are inherently limited in their capacity to describe ecological functioning. Deciding whether or not a particular landscape supports good ecological *functioning* is complex and will vary by species. This continues to be an active research focus of many landscape ecologists, however understanding structural patterns is useful for a very general picture of the condition of these "natural" areas.

What Are the Details of the Indicator Design? The indicator values would be determined following the process outlined in the *Pattern of Forest Landscapes* indicator (see page 38).

How Would the Indicator Data Be Presented? As with the Forest indicator, both the relative area of "core grassland" and "core shrubland" (Figure 23 and Figure 25) as well as the size of patches of "core grassland" and "core shrubland" (Figure 24 and Figure 26) would be presented.

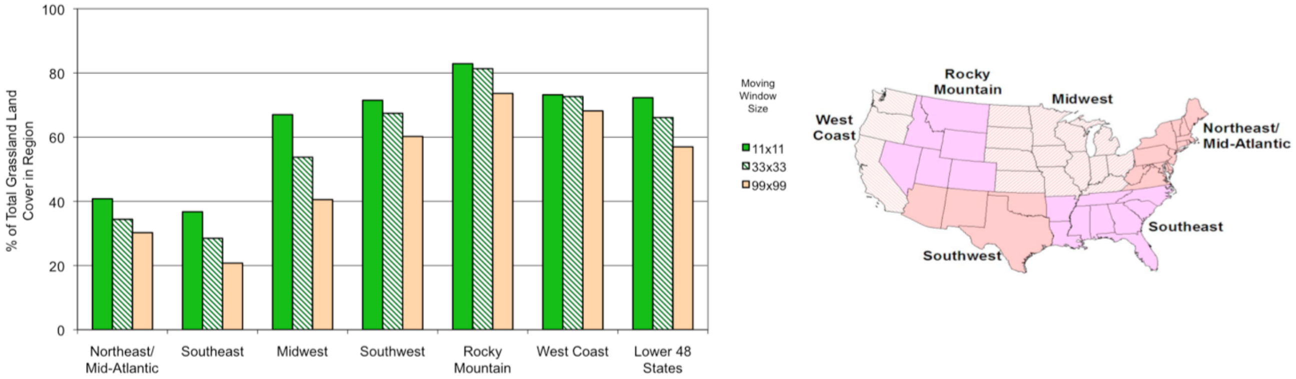


Figure 23: "Core grassland" area, as a percentage of total grassland land cover, regionally and nationally. The impact of the size of the "moving window" analysis tool (see text) can be seen by comparing the three panels. An 11x11 window contains 121 30-m pixels, which is equal to 26.9 acres (10.9 ha); a 33x33 window is 242 acres (98 ha); a 99x99 window is 2224 acres (900 ha). Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

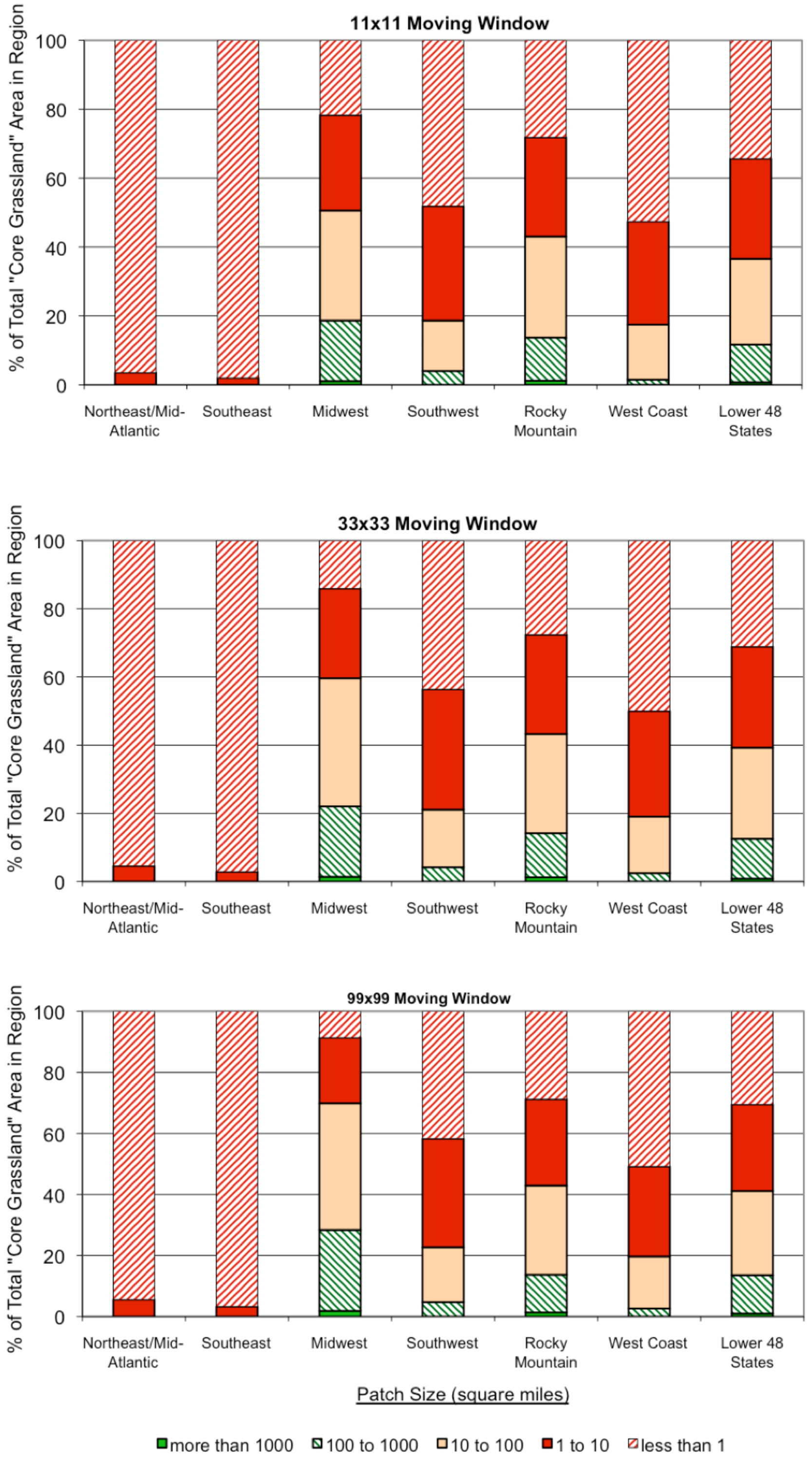


Figure 24: Patches of "core grassland" as a percent of total "core grassland" area, regionally and nationally. The impact of the size of the "moving window" analysis tool (see text) can be seen by comparing the three panels. An 11x11 window contains 121 30-m pixels, which is equal to 26.9 acres (10.9 ha); a 33x33 window is 242 acres (98 ha); a 99x99 window is 2224 acres (900 ha). Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

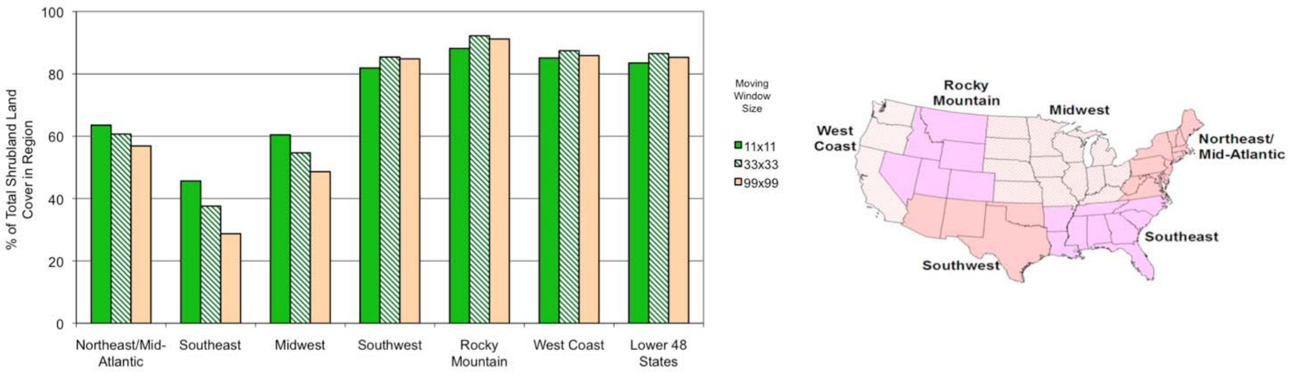


Figure 25: "Core shrubland" area, as a percentage of total shrubland land cover, regionally and nationally. The impact of the size of the "moving window" analysis tool (see text) can be seen by comparing the three panels. An 11x11 window contains 121 30-m pixels, which is equal to 26.9 acres (10.9 ha); a 33x33 window is 242 acres (98 ha); a 99x99 window is 2224 acres (900 ha). Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

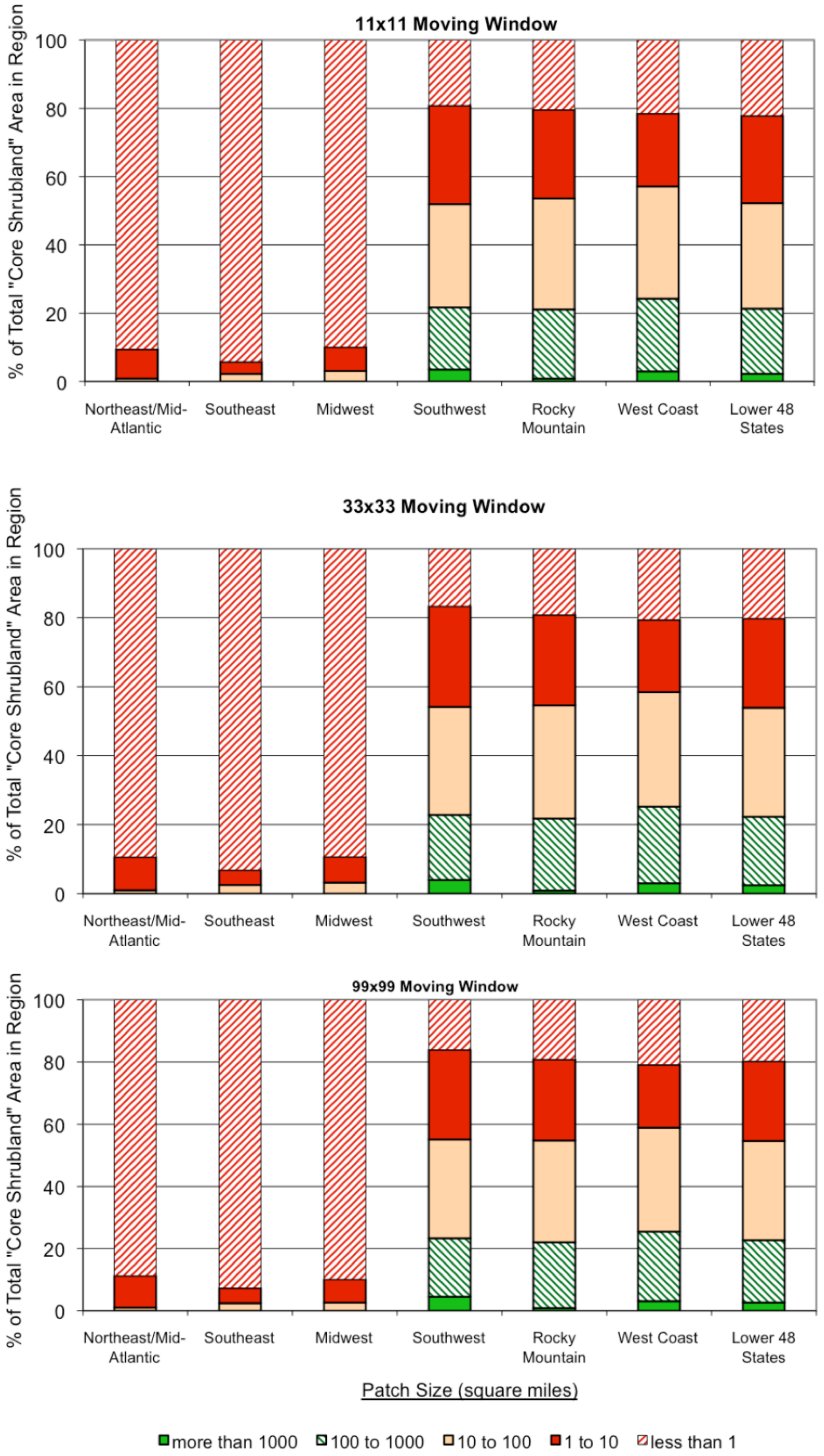


Figure 26: Patches of "core shrubland" as a percent of total "core shrubland" area, regionally and nationally. The impact of the size of the "moving window" analysis tool (see text) can be seen by comparing the three panels. An 11x11 window contains 121 30-m pixels, which is equal to 26.9 acres (10.9 ha); a 33x33 window is 242 acres (98 ha); a 99x99 window is 2224 acres (900 ha). Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

What Do the Data Show? Nationally for 2001, from 57 to 72% of grassland land cover was classified as “core grassland,” with increasingly less proportional area resulting from the use of larger moving windows (Figure 23). In contrast, about 85% of shrubland land cover was classified as “core shrubland,” regardless of moving window size. Data for several regions follow the general pattern for “core grassland,” although some regions had increasingly more or less “core shrubland” with increasing moving window size. For both “core grassland” and “core shrubland,” the Southeast region had the lowest percentages and the Rocky Mountain region had the highest percentages of total grassland or shrubland land cover, respectively. The Northeast/Mid-Atlantic and Southeast regions had the smallest patches of “core grassland”; these two regions plus the Midwest region had the smallest patches of “core shrubland.” The remaining regions had patch size distributions that were similar to the national averages.

For analysis using the 33x33 moving window:

- In 2001, more “core shrubland” (22%) than “core grassland” (13%), was in patches larger than 100 square miles.
- The Northeast/Mid-Atlantic and Southeast regions had relatively few patches of “core grassland” or “core shrubland” larger than 10 square miles. In the Midwest, there were few patches of “core shrubland” larger than 10 square miles, but about 60% of “core grassland” patches were above this size.
- The Midwest, followed by the Rocky Mountain region, had the most large patches of “core grassland,” with 22% and 14% in patches larger than 100 square miles, respectively.
- The West Coast, Southwest, and Rocky Mountain regions had more large patches of “core shrubland,” with 25%, 23%, and 22% in patches larger than 100 square miles, respectively.

For analyses using the 11x11 and 99x99 moving windows: For “core grassland” patches, the general trend of smaller patches with increasing moving window size was observed, although this was not the case for patches of “core shrubland.” As discussed in the section on the Forest indicator above, the reason for the observed relationship between “core shrubland” patch size and moving window size is most likely that, as the moving window size is increased, the analysis becomes less sensitive to small amounts of “non-natural” land cover. Thus, a 99x99 window may include just less than 10% “non-natural” with the central pixel carrying the “core shrubland” designation, whereas that same central pixel may not be included as “core shrubland” if most of the “non-natural” pixels are found in close proximity (i.e., an 11x11 moving window found more than 10% “non-natural” within it). Note that the data from the 33x33 moving window analysis are the ones included in the *2008 State of the Nation’s Ecosystems* report.

Urban-Suburban: Housing Density Change in Low-Density Suburban and Rural Areas

The 2002 Report's indicator, *Suburban/Rural Land Use Change*, was undefined. Several indicators proposed as part of the overall reporting framework help to address this topic. *The Pattern of "Natural" Landscapes* indicator will, to some extent, identify "natural" lands that are fragmented by residential-, commercial-, and transportation-related development. It is proposed that the Core National extent indicator include the amount of "natural" lands and croplands that are converted to development over time. It is likely that the Urban/Suburban extent indicator will capture how much of this conversion occurs within landscapes that are characterized by concentrated development (i.e., urban and suburban landscapes[12]). Finally, the *Proximity of Croplands to Residences* indicator will describe the increasing interspersion of development in and around our nation's agricultural lands.

The key missing component in the recommended suite of indicators is a metric that describes the *context* within which development is occurring. Even though the *Pattern of "Natural" Landscapes* and *Proximity of Croplands to Residences* indicators may show that more land is fragmented by development, it is essential for policy makers to understand if development is occurring in areas of low- or high-density housing, and if new development is itself low- or high-density. Note that the Task Group recommends that the indicator values should be reported without implying or explicitly stating that a specific housing density is optimal—there is no optimum and personal preference will dictate whether one thinks lower or higher densities are better.

What Is the Task Group Recommendation? The Task Group recommends an indicator that will focus on changes in housing density over time. Specifically, the number of new housing units in an area will be reported based on the density of housing units in that area at an earlier time. For example, the indicator will be able to differentiate between areas of low (or even zero if data permit) housing density to which houses have been added and areas of a higher housing density that have had a similar number of new housing units added. In addition, a map will accompany the indicator that will show starting and ending housing densities for areas across the country. The map will differentiate, for example, between areas of low density that remained at relatively low density and those that ended up at a considerably higher density.

The recommended indicator would rely on spatially-explicit data on housing density. The only detailed source of housing data is the decennial Census. However, because the areas for which housing density is summarized (i.e., Census blocks or block groups) have a wide range of sizes across the country, this may make them unsuitable for the analysis described below. There are several parallel efforts designed to recast the Census data in a more spatially-explicit manner. Data from one of these efforts is used here as well as in the *2008 State of the Nation's Ecosystems* report (SERGoM, see Appendix J) the other offers gridded data estimated for grid cells of a larger size[13].

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[12] See a discussion of urban and suburban indicators in Appendix E.

[13] A group at Columbia University's Center for International Earth Science Information Network (CIESIN) working on a gridded population database for the US (and the world); see: http://sedac.ciesin.columbia.edu/usgrid/methods.jsp.

Why Do We Care About This Topic? Human development depletes finite inventories of “natural” lands, as well as lands that have historically been managed as croplands[14]. Development often leads to more development, with more land being converted to expand transportation networks and accommodate housing and other uses to support an increasing population. Further, ecological effects of development extend well beyond actual construction sites. Development can, for example, fragment habitat, restrict the movement of animals, and lower stream quality.

At one extreme, development can dominate a landscape, with pockets of “natural” and agricultural lands interspersed in the developed matrix. The presence of these “islands” permits the area to support more wildlife than it would otherwise, and “natural” areas can effectively disconnect impervious surfaces associated with development, thereby slowing storm water runoff and contributing to infiltration and groundwater recharge. In the case of interspersed agricultural lands, urban residents can benefit from having sources of locally-produced fruits and vegetables, scenic beauty, etc.

Growth can occur within an otherwise developed matrix as these pockets of “natural” and agricultural lands are developed, although many such pockets are challenging sites to develop. Typically, growth is at the perimeter and can include “leapfrogging,” by which new development is located just past a greenspace at the fringe of the current urban or suburban area. At the other extreme, pockets of low-density development can be located in “natural” and agricultural landscapes. All of these patterns are sometimes referred to as *sprawl.*

New development, whether at the edge of suburbia or in rural areas, leads to new demands on infrastructure (e.g., causing long trips for commuters and crowded schools), and can have a fragmenting effect on surrounding “natural” and agricultural lands. Increasingly, residents have moved to experience “living alongside nature,” however the situation is analogous to Heisenberg’s uncertainty principle: in our efforts to observe nature by living within it, we alter the very thing we are trying to observe. This is an acceptable tradeoff for some, and a call to action for others who advocate land conservation and ideas such as “smart growth” (see Appendix D).

What Are the Details of the Indicator Design? Ideally, the indicator would capture fine-grained conversions of land to development. However, current technologies are unable to capture conversions on the scale of, for example, an individual house on a 20-acre lot. For this reason, it is proposed that new housing units themselves be used as a proxy for land conversions. Specifically, for regions across the country, the number of new housing units added since the last time point will be reported based on the housing density at the earlier time point.

The indicator should describe the context within which new development is occurring. In other words, is new residential development occurring in areas with low, medium, or high housing density? Such information would be relevant to policy decisions, such as zoning restrictions

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[14] Note that the Pattern of “Natural” Landscapes indicator clearly equates croplands more with development than with “natural” lands by reporting on areas that lack either “natural”-developed or “natural”-cropland edges. Such an approach is consistent with that indicator’s focus on how human activities (agriculture and development) affect the overall pattern of “natural” lands. <u>This</u> indicator, in contrast, is designed specifically to explore the patterns of <u>development</u> in particular, with respect to its effect on either “natural” lands or agriculture

placed on housing density. Note that the *type* of new residential development (e.g., whether or not it is associated with mixed-use development that can reduce the distances traveled in vehicles, auto emissions, etc.) is not addressed by this indicator; such data are not currently available, yet even if they were including them might make the indicator too complex.

There are at least four different possible development scenarios for an area (Figure 27). Note that this discussion utilizes Census blocks, although, as discussed above, grid-based data were used in the analyses for this indicator.

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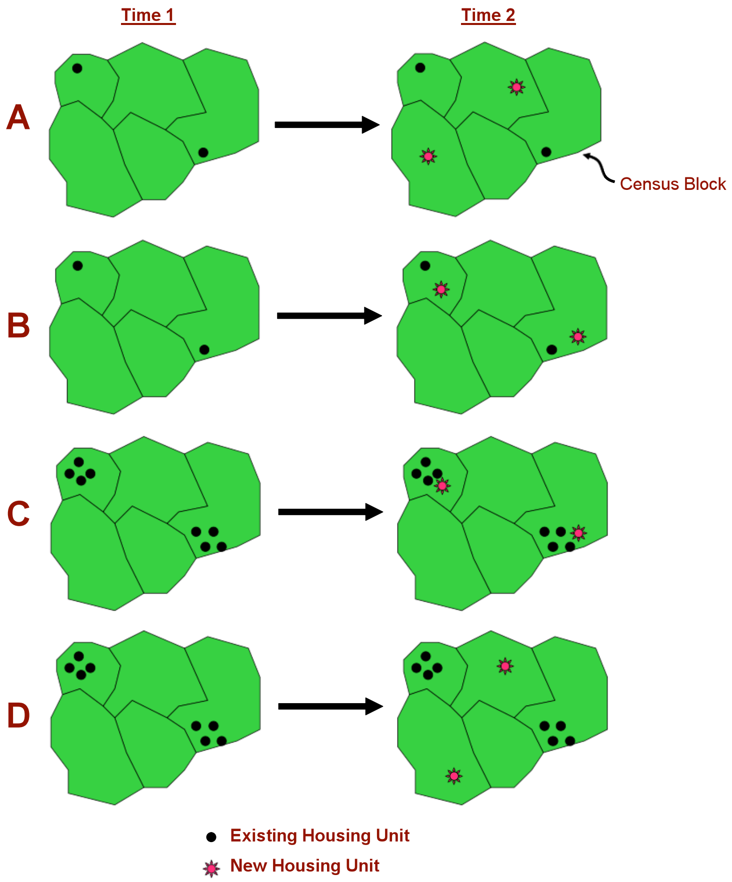


Figure 27: Sketch of four hypothetical development scenarios for the suburban / rural land use indicator: (A) lower density, scattered housing characterizes both time 1 and 2; (B) pockets of lower density, scattered housing are transformed into clusters of higher-density housing; (C) higher-density, clustered development characterizes both time points; and (D) higher-density, clustered housing and areas of less-dense, scattered housing.

The goal for the indicator is to characterize the context in which land is being converted to development. The rationale for choosing to present data based on the housing density in the earlier time period (e.g., 1990 v. 2000) is that this focuses on the context within which new homes are added, rather than the resulting housing situation. At a minimum, the two most recent time points of data would be included in this indicator; as additional time points become available, an approach for showing the overall time trend will need to be developed.

The scenarios depicted in Figure 27A and B would be typical of *exurban* areas, with analysis units (Census blocks in this case) in Figure 27A having relatively lower housing densities than in

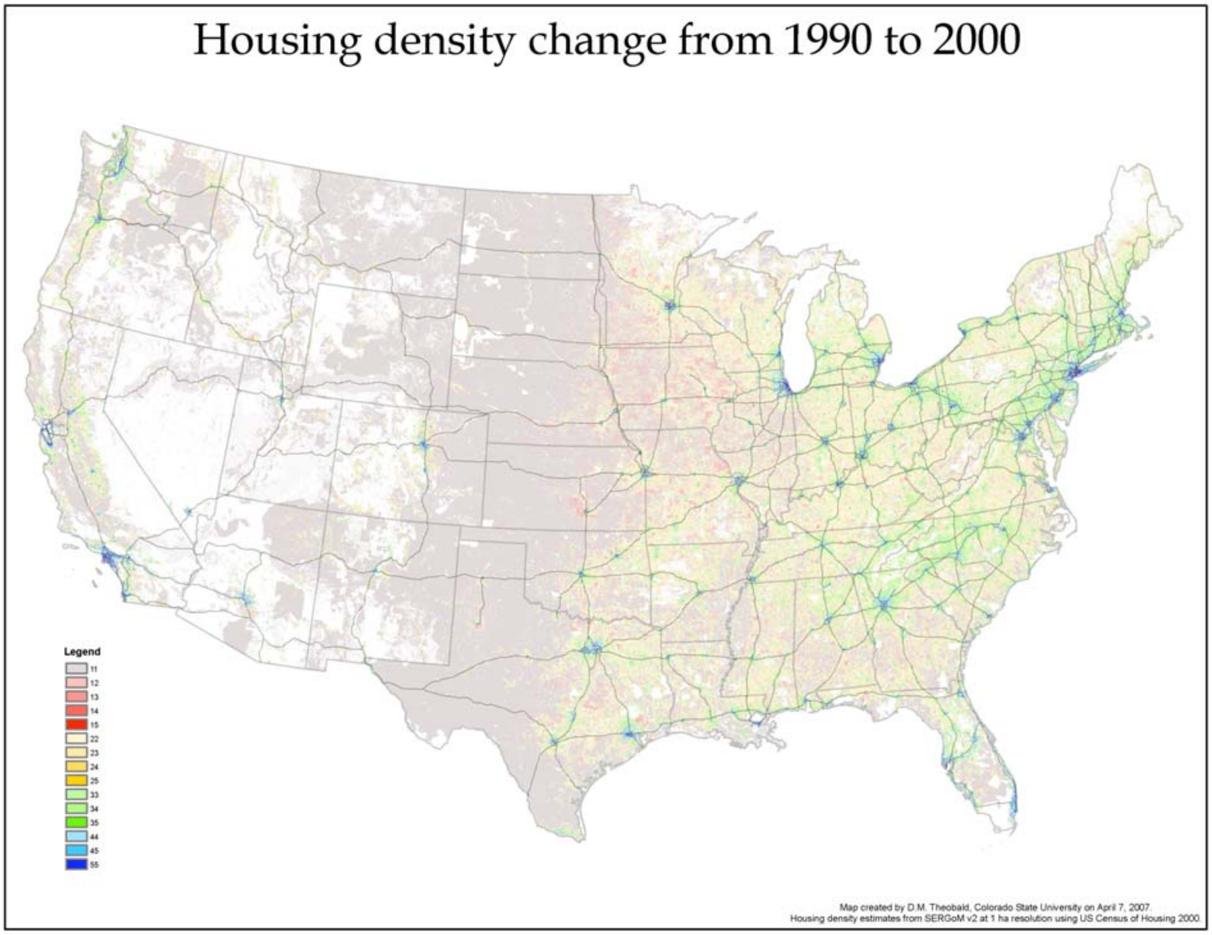
Figure 27B. In contrast, panels C and D in Figure 27 would be more typical of low-density suburban areas, with Figure 27C having the highest housing density. When presented on a graph, the indicator values would distinguish between the development scenarios illustrated by Figure 27A–D (i.e., analysis units with little or no density in which houses were built). The proposed mapping strategy outlined below would provide further distinctions about the resulting density in any given area.

How Will the Indicator Data Be Presented? Data have been analyzed for the conterminous U.S., both for use in this report as well as the *2008 State of the Nation's Ecosystems* report by David M. Theobald at Colorado State University. Dr. Theobald has developed the SERGoM dataset to estimate housing density for square grid cells that are 100 m on a side (see Appendix J for more details).

The recommended strategy for a map to accompany graphed data is as follows. The map would provide critical information about current housing densities compared to earlier housing densities. Grid cells would be shaded based on *both* their densities at the earlier and more recent time point. A fairly small number of combinations would be used, so that a standard color scheme would be able to differentiate the combinations shown. An example set of categories is shown in Table 6. With such a map (see Figure 28), one could differentiate between areas of low density that remained low density (e.g., color code 1) and low density areas that changed to a substantially higher density (e.g., color code 3). It is likely that some of the higher color codes (e.g., 9 and 10) may not be necessary given that the focus of this indicator is at the suburban/rural interface, rather than in areas that would solidly be classified as suburban. Data on the number of housing units added in areas with various pre-existing housing densities would be graphed (Figure 29).

Table 6: Color Scheme for Indicator Map (Figure 28)

		2000 Housing Density (acres per household)				
		>100 (lowest)	10 to 100	1 to 10	0.1 to 10	<0.1 (highest)
1990 Housing Density (acres per household)	>100 (lowest)	11	12	13	14	15
	10 to 100		22	23	24	25
	1 to 10			33	34	35
	0.1 to 10				44	45
	<0.1 (highest)					55


Housing density change from 1990 to 2000

Map created by D.M. Theobald, Colorado State University on April 7, 2007.
Housing density estimates from SERGoM v2 at 1 ha resolution using US Census of Housing 2000.

Figure 28: Map of housing density change estimated between 1990 and 2000. Colors relate to scheme detailed in Table 6. Blue values (class 55) represent high housing densities both in 1990 and 2000, whereas the gray values (class 11) represent the lowest housing densities for both time periods. Classes 12 through 15 represent areas with the lowest housing densities in 1990 with increased housing densities estimated for 2000. Estimated housing densities by D.M. Theobald (Colorado State University), based on U.S. Census Bureau data.

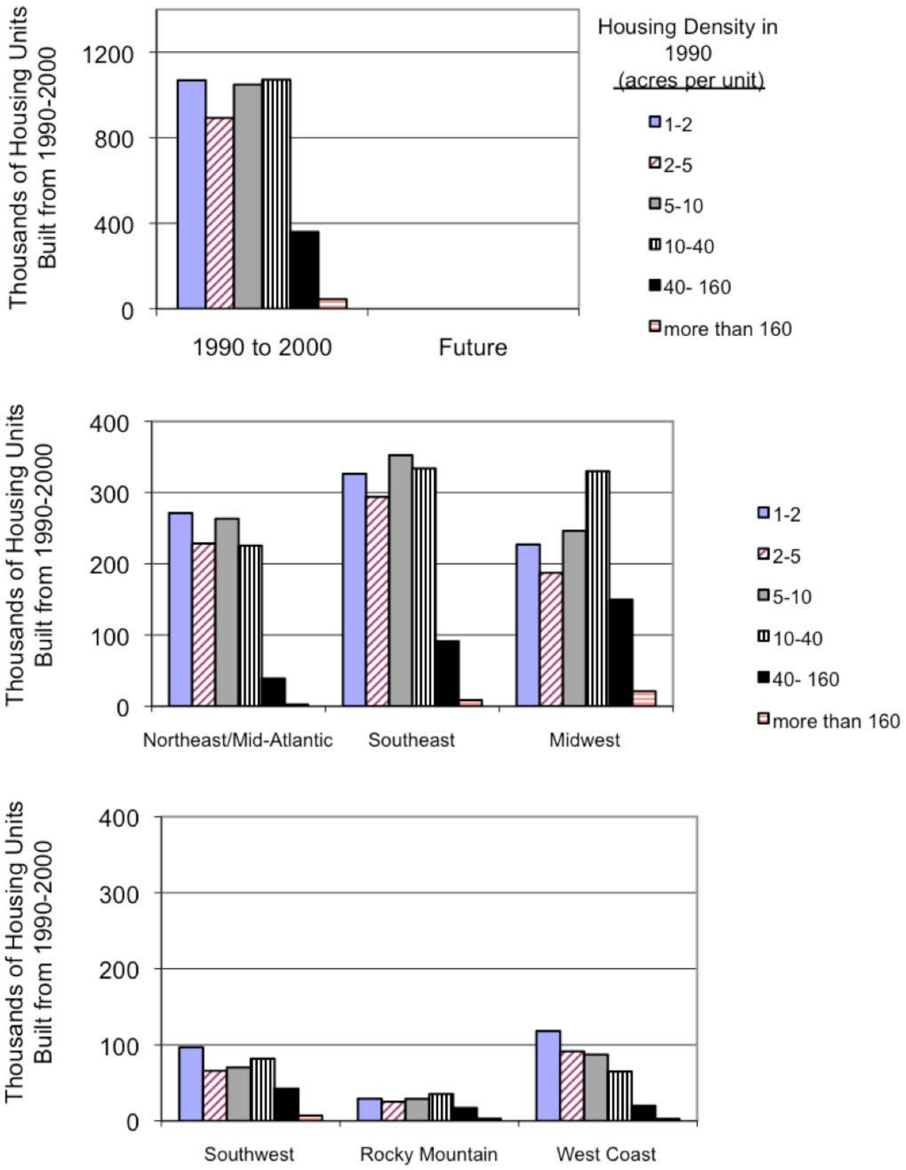


Figure 29: Housing units added between the 1990 and 2000 censuses, both nationally and by region (see Figure 4 for a description of regions). The color of the bars represent different estimated housing densities in 1990 (lower graph uses same legend as upper).

What Do the Data Show? The map of housing density changes (Figure 28) reveals the landscape pattern associated with the construction of new homes. Reds and dark yellows indicate where housing density increased on lands that had very low housing densities in 1990. Conversely, greens and blues are areas that already had higher housing densities in 1990. The detailed data (Figure 29) suggest that,

- Nationally, between 1990 and 2000
    - Just over 1 million housing units were built on land with preexisting housing densities of one housing unit per 1–2 acres—the highest preexisting housing density reported here.

    - Just under 2 million housing units were built on land with a preexisting density of 2–10 acres per unit.
    - About 1.1 million housing units were built on land with a preexisting density of 10–40 acres per unit.
    - About 360,000 housing units were built on land with a preexisting density of 40–160 acres per unit.
    - Forty-five thousand housing units were built on very sparsely settled lands (one house on 160 acres or more).
- More housing units were built over this time period in the East and Midwest than in the western regions.
- The greatest number of housing units added at lower preexisting housing densities (one house on 40 acres or more) was in the Midwest.

What this Indicator Is Not. While initial ideas centered on a direct indicator of *sprawl*, the Task Group realized that there are no generally accepted standards dictating what type of land conversion patterns might be considered *sprawl*, or conversely, perceived as “smart growth”. That is, there is no universally-accepted definition of *sprawl*. Rather, this would appear to be a phenomenon that is defined and addressed (or not) by local planning and zoning boards, frequently in a political context. For example, what may be deemed as acceptable low-density development in one area maybe viewed as unacceptable in another—even if the biophysical conditions in both areas are very similar. Further, there will be many who find the loss of “natural” land connectivity, for example, to be acceptable given the gain in more rural living situations (see Appendix D).

“Natural” Lands in Highly Managed Landscapes: “Natural” Lands in the Farmland Landscape and “Natural” Lands in the Urban and Suburban Landscape

The 2002 Report included two indicators that dealt with the presence of “natural” lands within highly managed landscapes—one in the Farmlands chapter and one in the Urban and Suburban Areas chapter. The Farmlands indicator (*Shape of “Natural” Patches in the Farmland Landscape*) was designed to report the percent of “natural” patch area in three different shape patches: compact (e.g., circular), intermediate, and elongated (e.g., narrow rectangular). There was insufficient time and resources to prepare the Farmlands indicator for the 2002 Report. The Urban and Suburban Areas indicator (*Patches of Forest, Grassland and Shrubland, and Wetlands*) presented data on the size distribution of “natural” patches within polygons that were characterized by residential and commercial development.

Both of these indicators had been produced from full committee processes, and no particular shortcomings had been identified. However, they by default fell under the purview of the Task Group. It is worth mentioning that there was a modest amount of debate within the Task Group regarding the use of patch-based metrics. The critics, who argue that defining habitat patches on the landscape carries with it a very human-centered view of things, were less concerned when applying patch statistics to polygons such as those created by the farmland landscape or urban and suburban areas definitions. The advocates argue that the concept of patches is more easily assimilated by the target audience for *The State of the Nation’s Ecosystems* compared to some other concepts.

What Is the Task Group Recommendation? The Task Group recommends an indicator design that closely resembles the one proposed for the *Pattern of “Natural” Landscapes*, *Pattern of Forest Landscapes* and the *Pattern of Grassland and Shrubland Landscapes*. That is, the indicator would report the percent of small parcels (~ ¼ acre) of “natural” land cover in the farmland landscape (or urban and suburban landscape) that can be classified as “core natural.” As for those indicators, it is recommended that a number of moving window sizes be used in conjunction with several density thresholds to determine whether or not there is sufficient “natural” land cover within a moving window to classify the central pixel as “core natural.” For the purposes of this report and the *2008 State of the Nation’s Ecosystems* report, a single condition was used for this analysis: a moving window that had been reduced to the size of a single pixel in the land-cover map (i.e., all “natural” pixels within the farmland and urban-suburban landscapes were included, and patches were constructed from them). The intention was to complement those data with several other moving window size, but time and resources did not permit that.

Why Do We Care About This Topic? Many landscape mosaics are characterized by human development or agriculture, yet include significant amounts of “natural” lands. These “natural” lands help to control erosion and movement of sediments, facilitate groundwater recharge, provide critical habitat for wildlife, and serve other important ecological functions. In landscapes dominated by agriculture, the size (and shape) of these often small and isolated remnants, along with restored conservation areas (e.g., CRP land), directly influence the amount and type of ecosystem services provided—beyond crop production.

Further conversion of land to development (or cropland) in these areas can fragment the existing "natural" lands, creating new kinds of habitats that may be colonized by generalist native species or exotic species.

Smaller patches of "natural" habitat generally provide lower-quality habitat for plants and animals (although this is not necessarily true for wetlands) and provide less solitude and fewer recreational opportunities for people. Smaller patches of habitat favor common, human-tolerant species like squirrels, white-tailed deer, starlings, and sparrows, over less common species that require larger areas, such as some birds (pileated woodpeckers, broadwinged hawks, and many warblers), mammals (bears, mountain lions, wolves, coyotes, mink, otters, and weasels), and amphibians.

Small patches have little or no "interior" habitat—that is, habitat that is insulated from outside influences by a significant buffer zone. Since some species thrive only in interior habitat—where there is a relatively large and contiguous area of forest, grassland, or other "natural" cover (see the core national adjacency indicator, and the forest and grassland-shrubland connectivity indicators), small areas may not provide habitat for these species. Beyond simply their area, the shape of "natural" patches will affect the amount of interior habitat available and, therefore, may affect the quality of habitat. Of course, large but narrow strips may tend to have lower habitat value because of the lack of much area that is buffered, however these same strips of land may function quite well for erosion and sediment control.

In some cases, recent activities in urban and suburban landscapes may have less impact on the size of "natural" patches than past ownership and land use practices. For example, historic zoning policies may have left some blocks of "natural" lands untouched by development. In other cases, long-time property owners may have prevented lands from being subdivided and developed.

What Are the Details of the Indicator Design? The recommended indicator utilizes a protocol very similar to that used for the Core National, Forest and Grassland-Shrubland pattern indicators. Specifically, the density of "natural" pixels within moving windows of several sizes would be determined for each "natural" pixel within polygons associated with the farmland landscape and urban and suburban landscapes[15].

How Will the Indicator Data Be Presented? Ideally, data for these indicators would be presented with an interactive component that would permit the reader to adjust the moving window size as well as the density threshold used to determine whether or not a particular pixel is considered "core natural." For the purposes of this report and the *2008 State of the Nation's Ecosystems* report, in part because the latter does not have an on-line component, a single moving window of size unity (i.e., a single grid in the land-cover maps) was used for the analyses. Thus, the data presented in Figure 30 and Figure 31 report simply the size of patches of "natural" land cover in the farmland and urban-suburban landscapes, respectively.

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[15] see Appendix E and Appendix F. The definitions of both the "farmland landscape" and "urban and suburban areas" were developed by the Heinz Center as part of the 2002 Report process. Both definitions were conceived in order to delineate polygons that would be largely characterized by croplands or development, respectively. The Center did not benefit from a high degree of input from committee members specifically on these definitions, and we have recently re-defined these definitions with input from the Task Group.

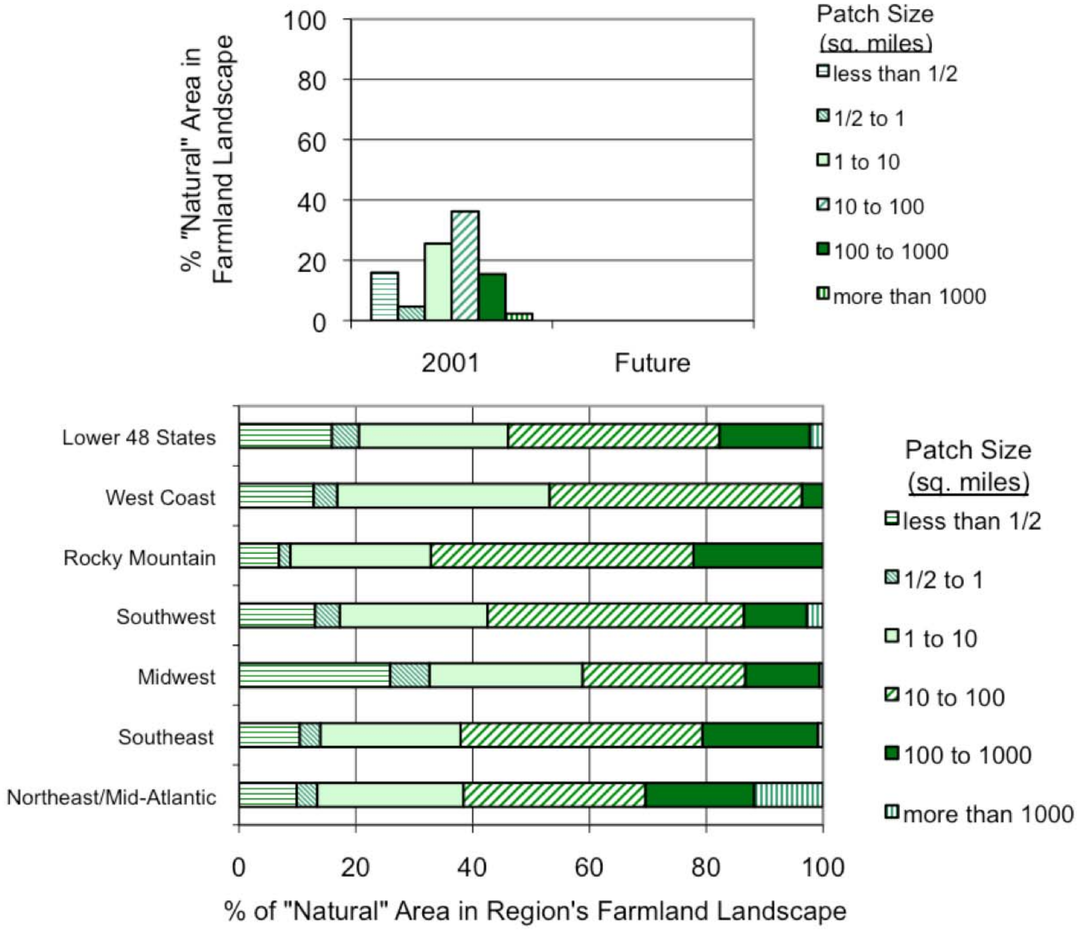


Figure 30: Patches of "Natural" land cover within farmland landscapes across the conterminous U.S. Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

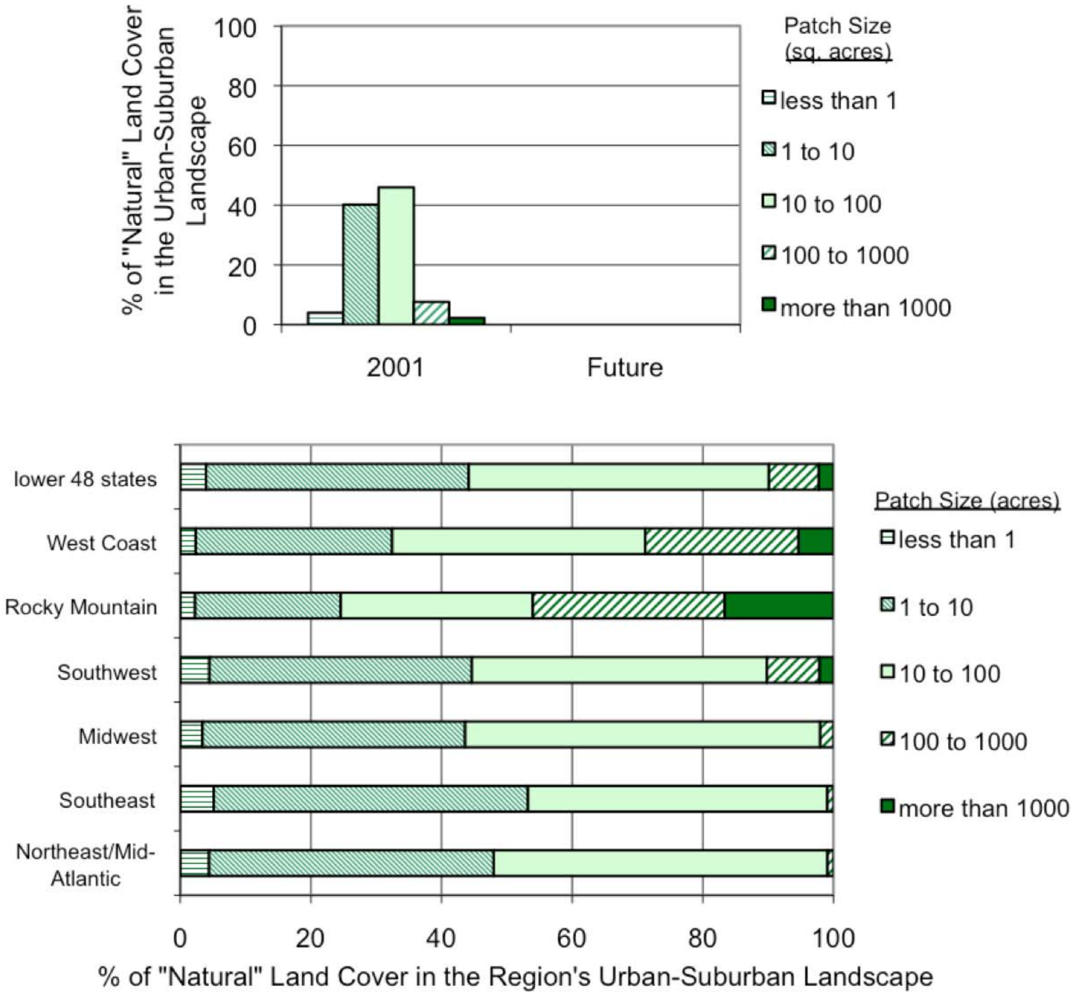


Figure 31: Patches of “Natural” land cover within urban-suburban landscapes across the conterminous U.S. Data source: Multi-Resolution Land Characterization (MRLC) Consortium and ESRI (road map); analysis by the USDA Forest Service and the U.S. Environmental Protection Agency.

What Do the Data Show?

“Natural” Lands in the Farmland Landscape

- In 2001, 16% of the “natural” patches in the farmland landscape were less than ½ square mile (320 acres). About 60% of patches ranged from 1 to 100 square miles; there were few patches of ½ to 1 square mile and even fewer larger than 1000 square miles.
- The Northeast/Mid-Atlantic had the highest proportion of “natural” area (30%) in patches larger than 100 acres, and several very large patches accounted for 12% of the total “natural” area in the region; the West Coast had the lowest proportion of “natural” area (4%) in patches larger than 100 acres.
- The Midwest had proportionally more “natural” area (33%) and the Rocky Mountain region had proportionally less (9%) in patches smaller than 1 acre than the other regions.

“Natural” Lands in the Urban-Suburban Landscape

- In 2001, 90% of “natural” patches in urban–suburban landscapes of the lower 48 states were between 1 and 100 acres; about 2% of “natural” lands were in patches larger than 1000 acres.
- The Rocky Mountain region had the most “natural” land in large patches in its urban and suburban landscapes—nearly 50% in patches of 100 acres or more; the West Coast also had a substantial proportion (nearly 30%) of patches 100 acres or larger.
- The size distribution of “natural” patches in urban and suburban landscapes in the Southwest matched the distribution for the lower 48 states.
- In the Northeast/Mid-Atlantic, Southeast, and Midwest regions, virtually all “natural” land occurs in patches of 100 acres or less.

What Will this Indicator Imply About the Shape of “Natural” Lands? At the beginning of this section, the issue of shape was mentioned—specifically that the proposed indicator takes shape into account to some extent. While moving windows of various geometries could be used, the standard has been to use one that is square. This has a tendency to consider the landscape through a series of filters (i.e., window sizes) that are square in shape, whereas landscapes are not necessarily arranged with such a geometry naturally. However, this bias can be interpreted in a positive manner.

Consider two landscape scenarios. For the same area of “natural” land, one scenario is arranged in a square patch and another is arranged in a long, narrow strip. The former scenario would have more *interior* habitat area (i.e., that habitat which has more of a buffer between it and the neighboring land use/land cover). If one considers interior habitat to be a key factor in determining habitat quality for an area, then the square patch would be seen as having higher habitat value.

Clearly, if we had two complementary analyses, one showing the size of habitat patches and the other showing their shape, considerable information would be available. Using the assumptions above, one would conclude that an area with lots of long, narrow patches would, in general, have a lower habitat value than would areas with more circular (or square) patches.

Because the proposed analysis would rely on a square moving window, patches that are long and narrow would essentially be excluded because there would be large amounts of “non-natural” land cover within the square moving window. While this will cause the proposed indicator to understate the overall area of “natural” areas within these landscapes—those areas that are reported will be more square or circular and less long and narrow.

This would appear to be a reasonable compromise in order to limit the characterization of these “natural” areas to a single indicator in each system chapter. It is worth noting that the Center anticipates reporting on the acreage of all “natural” areas within these two landscape types (urban and suburban and farmland landscapes) within the extent category.

APPENDIX A: NATIONAL LAND COVER DATASET (NLCD)

In the 1990s, a federal interagency consortium was created to coordinate access to and use of land cover data from the Landsat 5 Thematic Mapper. Using Landsat data and a variety of ancillary data, the consortium processed data from a series of 1992 Landsat images, to create the NLCD on a square grid covering the lower 48 states. Each square in the grid, or "pixel," is approximately 100 ft on a side (30 m).

Each pixel was assigned one of 21 land cover classes, which are described at http://landcover.usgs.gov/classes.asp. The steps of this classification process, which can be found in detail elsewhere (see Vogelmann et al. 2001; Vogelmann et al. 1998), are summarized here. First, an automated process is used to create clusters of pixels for a given regional area. Second, these clusters were interpreted and labeled with the help of aerial photographs. Third, in cases where clusters of pixels included multiple land cover types (i.e., "confused clusters"), models that utilize ancillary data, such as elevation or population density, were used to help assign land cover classes. Finally, lands that are bare—especially clear cuts and quarries—and many grass areas, such as parks, golf courses, and large lawn, are not easily distinguished from other land cover classes during the automated process, so a process of on-screen verifications was used as clarification. These four steps were the general process, and additional steps were taken in certain regions in order to further improve the accuracy of classifications (see http://landcover.usgs.gov/accuracy for a discussion of NLCD error analysis).

Note that classification of pixels was based in part on the character of surrounding squares in the grid; thus, a pixel of grass-like land cover surrounded by residential pixels would probably be classified as "urban and recreational grasses" rather than as "pastureland." Where appropriate, the agencies also made use of data from both the Census Bureau and the U.S. Fish and Wildlife Service's National Wetlands Inventory data to help make such distinctions. Satellite data offer an unprecedented opportunity to classify land cover on a consistent basis over very large areas (i.e., the entire country). However, the accuracy of any classification is not perfect. The accuracy of satellite-derived classifications is related to many factors: amount of data available (i.e., many dates of imagery rather than just one), the detail of the required land cover information (i.e., forest vs. deciduous forest vs. sugar maple/beech/yellow birch), classification methods, computing power, and, of course, time and money. Assessments of the NLCD for the eastern United States indicate an accuracy of approximately 80% or higher for general land cover categories (e.g., forest, agriculture, developed). Accuracy assessments for the western United States are currently under way. Improving technology and techniques offered the potential to increase accuracy of the 2001 NLCD recently released by the Multi-Resolution Land Characterization Consortium. The land cover classes associated with the 30-m (100-foot) square pixels were grouped for the different ecosystems as follows (the number in parenthesis is the NLDC land cover class reference):

- Forests: deciduous (#41); evergreen (#42); mixed forest (#43)
- Croplands: pasture/hay (#81); rowcrops (#82); small grains (#83); fallow (#84); orchards/vineyards/other (#61)
- Grass/Shrub: shrubland (#51); grasslands/herbaceous (#71); bare rock/sand/clay (#31)
- Water: open water (#11); wetlands (#91 & #92)
- Developed: low-intensity residential (#21); high-intensity residential (#22); commercial/industrial/transportation (#23); urban/recreational grasses (#85)
- Other: quarries/strip mines/gravel pits (#32); transitional (#33); perennial ice/snow (#12)

APPENDIX B: CONSIDERATION OF AN INDICATOR OF ROAD DENSITY

The Task Group desired to include an indicator of road density—either broadly conceived or reported on a watershed basis—but decided that the Pattern of Natural *Lands indicator (see p. 20) adequately captured roads in the manner in which an indicator devoted to road density would have. This indicator is discussed here given the great interest expressed in it by the group. Further, this discussion includes measures of the distance to the nearest road because it is very much related to road density.*

Roads have obvious benefits to humans, namely transportation of people and goods. Roads also provide access for myriad human activities. As human development spreads across the landscape, so do roads. Roads are now ubiquitous elements of the landscape—they themselves have a pattern, and their presence can, in turn, create patterns of other landscape elements. What follows is a general discussion of roads, followed by a discussion of the indicators proposed by the Task Group.

Why do we care about roads from an ecological perspective?

The following is an abbreviated list of ecological reasons to care about roads on the landscape (see Forman 2004):

- animals are killed by vehicles, which can have population-level effects, especially for larger species that have small populations and reproduce slowly; in addition, human health is often negatively impacted by such accidents.
- roads generally are associated with residential development, and associated light pollution, predation of wildlife by domestic pets, etc.
- habitat is lost due to the conversion of land necessary to accommodate the footprint of roads and roadsides.
- habitat adjacent to roads can be degraded because:
    - animals may avoid the area around roads due to the noise.
    - animals may avoid roads due to the change in the physical habitat (e.g., openings in the tree canopy), thereby creating a barrier to movement of organisms; this varies greatly from organism-to-organism.
    - increased exposure to wind and sun can cause desiccation adjacent to roads.
    - contaminants from tires, fuel, and other vehicle materials (e.g., brake linings) are deposited on the road surface and can contaminate the nearby soils, be blown into adjacent habitats, and wash from the road surface into adjacent streams and lakes.
    - roads can be conduits for the spread of non-native (invasive) species, either because of favorable new habitats and/or because the movement of seeds and organisms is facilitated by the road network.
    - soil erosion is a common phenomenon in the area around roads, which can lead to increased sedimentation in adjacent streams; increased run-off from impervious road surfaces can also lead to increased "flashiness" of stream flows.
    - roads can sever connections between floodplains/wetlands and the stream network.

Humans benefit from the road network in obvious ways (transportation, jobs, etc.), but this is not without limits:

- people are able to access fairly remote places, for purposes including hiking, hunting, fishing, and natural resource extraction, thanks to the road network.
- once in the backcountry, however, humans trying to experience solitude are confronted with the pervasive nature of roads.
- as mentioned above, vehicle-animal collisions can injure or kill humans.

The following reasons were identified earlier as the prime reasons for proposing road-related indicators in terrestrial and freshwater systems. Note that some of the effects of roads listed on the previous page are not equally captured by the following indicators—please see discussion on p. 5 with the table about how the Group's concerns map onto the indicators):

- ***In terrestrial systems***, the overall network of roads describes the accessibility of areas to humans (implications for hunting, spread of invasives, etc.). Larger roads are, in general, more significant barriers to animal movement than are small roads. Areas with no roads are more natural and are sought out by hikers seeking a wilderness experience, and they serve as refuges for other animals. Roads also have chemical and physical—especially thermal—effects on their surroundings.

- ***In freshwater systems***, roads sever connections, both in terms of water flow and the movement of organisms, between rivers and their floodplains as well as among interconnected wetlands. Increased sedimentation, alteration of stream flow, and the introduction of contaminants were also major concerns from a freshwater perspective. Watersheds that lack roads (or have low road density) provide a higher degree of refuge for plants and animals.

How does scale matter?

The behavior of a road density indicator is completely dependent on scale of the analysis unit relative to the scale of the patterns of roads. For example, if the analysis unit is of a continental scale, little is learned about the spatial pattern of roads within the continent—all that would be know is that the road density for the continental US is about 1.1 miles per square mile (Forman 2004). Taken to the other extreme, road density within an exceedingly small "window" will yield a pattern that is just an exact replica of the road network.

It has been argued that road density is not a spatial indicator (e.g., Theobald 2003), and the two extreme examples above support that. However, this does not appear to be universally valid. Spatial information will be gained if the scale of the analysis unit is chosen both to make sense ecologically and to be of a scale that resembles the pattern of the roads (i.e., the analysis unit is large enough to capture multiple roads within it, although it is also small enough to reveal areas of low or zero road density). Alternatively, there should be variation in the amount of area in different density classes because roads are not evenly distributed on the nation's landscape.

Another way to look at this would be to consider two land cover types. Knowing their area for the country as a whole reveals nothing about their regional distribution, let alone the extent to which they intermingle on the landscape. However, as the analysis unit is reduced, more understanding can be gained about the juxtaposition of these two cover types. There is most likely an optimum analysis unit size based on the investigator's question, because an exceedingly small analysis unit will again reveal nothing about pattern because, in a given location, it will contain only a single cover type.

There does not seem to be a scale-related concern for the distance to nearest road metric—increasingly larger areas are observed around a point in search of the nearest occurrence of a road; it is not possible to choose an analysis scale that somehow skews the results, although the scale of the underlying data do influence the accuracy of estimates (see below).

In order to compare the "performance" of these two indicators, however, scale most definitely must be taken into account. Using an example from a recent publication from The Wilderness Society on the Monongahela National Forest (MNF)[16] (Fleming et al. 2004), we see the percent of the landscape that is within a specified distance of a road (first graph below). In the same study, the investigators measured road density by passing a 1-mile square moving window across the landscape (these data are summarized in the second graph below).

FIGURE 4.

Percent of Landscape within Various Road Effect Zones Relative to Land Ownership

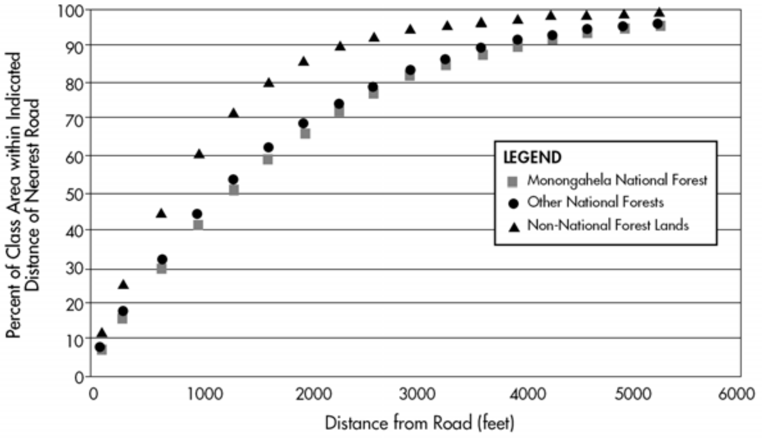
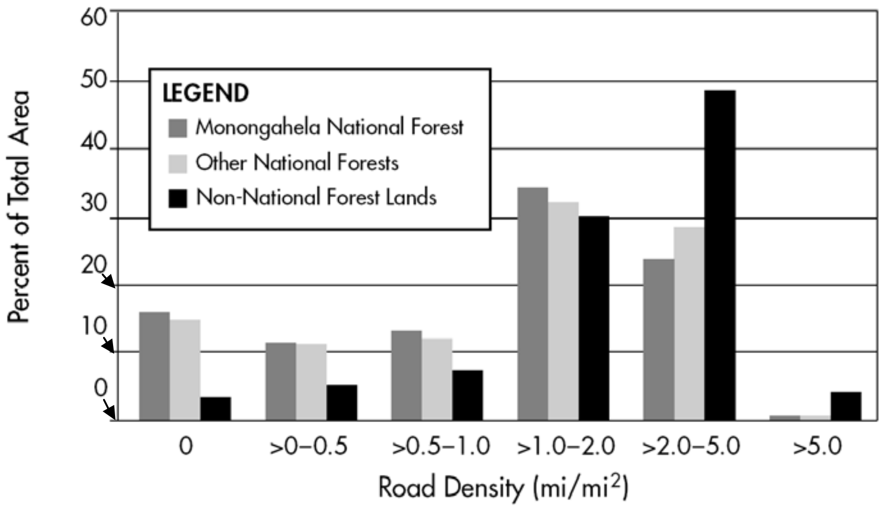


FIGURE 2.

Percent of Study Area in Different Road Density Categories Relative to Land Ownership



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[16] http://www.tws.org/Library/Documents/MonongahelaRoadsReport.cfm

This analyses reveals two important relationships between these indicators (G.T. Bancroft, personal communication). The interpretation of the second graph is aided by use of the first. That is, we can evaluate the decision to use a 1-mile square window by adding a vertical line on the upper graph at about 3700 ft., which is equivalent to the nominal dimension describing the square window used to measure road density (the distance from the corner of the moving window to the opposite corner of the center pixel). Therefore, about 10-15% of the pixels of the MNF would have had no road inside the moving window used to measure road density. In fact, this agrees fairly well with the zero road density class shown in the lower graph (about 15% of the total area had a road density of zero). This implies that if a moving window of about 2-miles on a side had been used, the zero road density class would have been virtually empty (i.e., a road would have been present everywhere the moving window was placed) ; conversely, had a moving window of only 0.5-miles on a side been used, then about 40% of the area would have had zero road density.

A second relationship between these two metrics is seen by considering the points to the left of the dotted line added to the upper graph. For each pixel that had a road within less than about 3700 ft., there would have been a non-zero road density measured. However, the distance to nearest is only a binary, yes/no, indication that a road is within the specified distance, and does not indicate anything about the amount of roads within that distance.

This begs the question of whether or not there is a relationship between these two metrics. Clearly, the answer has two parts. The discussion above suggests that the shape of the distance to nearest road distribution (upper graph) directly impacts the proportion of area in the zero density class for any given analysis unit (moving window size). In cases where roads are detected for the density measurement, is density correlated with distance to nearest road? Tom Bancroft is helping us get access to the data behind these plots from the MNF in order to test this, and we expect to have this prepared for the December meeting. In absence of these data, results from the case study presented in a subsequent section of this document, suggest that road densities are generally correlated with distance to nearest road.

It is worth noting that the scale of the underlying grid data will impact the accuracy of the estimates of distance to nearest road. For example, Riitters and Wickham (2003) used road data on a 30-m grid, whereas those doing the MNF analysis used a 321-m grid (i.e., 1/5 mile). Thus, the accuracy of the MNF values will be lower. There may be more to understand about this, but it would seem that at a minimum, the implied accuracy of the estimates based on the grid size at least should not over-state the spatial accuracy of the underlying road data.

How do the potential indicators map onto the "why do we care" questions?

The above discussion on scale touched on the issue of whether or not these two metrics are well-correlated. What follows is an attempt to partition the "why do we care" questions into those that might best be answered by a metric of road density and those that might best be informed by the distance to the nearest road (please refer to the more extensive list of questions above in section "Why do we care?").

Why do we care?	Best Captured By:

	Road Density	**Distance to Nearest Road**
road collisions	✓	
habitat loss	✓	
desiccation	✓	
pollution (airborne)	✓	
pollution (waterborne)	✓	
avoidance zone (refuge)		✓
barriers to movement	✓	
conduits for invasives	✓	
soil erosion/sedimentation	✓	
severed connections (wetlands and floodplains)	✓	
human refuge (solitude)		✓
human access (recreation & resource extraction)		✓

<u>How to evaluate the indicators for the various ecosystem types…</u>

The group has considered applying one or both of these indicators to multiple ecosystem types—is this really feasible? Yes, it appears to be possible, however, there are complications. It is easiest to discuss this separately for terrestrial and freshwater systems.

For individual terrestrial systems (i.e., forests, grasslands, shrublands), there are two distinct approaches that would be valid for evaluating these metrics. One would be simply to do the calculations for every pixel of, for example, forest land cover across the country. The other option would be to create discrete “forest areas,” for example, and evaluate the metrics within these areas (this would be analogous to the “farmland landscapes” that were defined in the 2002 *State of the Nation’s Ecosystems* report). Both methods have their pros and cons.

In order to define “forest areas,” a set of definitions would be required that are not currently available, and may or may not be readily accepted by the user community. However, with these areas in hand, one could limit road density analyses within them. It is conceivable that only roads within these forest areas could be considered for the distance to nearest metric.

On a pixel-by-pixel basis, road density would be done by moving window. As discussed above, road density should be applied within an analysis unit, whose size has ecological meaning. If a moving window were used, the MNF example would suggest that it might be wise to evaluate road density for several window sizes, and then compare and contrast the resulting distributions—both too small or too large of a moving window will produce a density distribution that lacks substantial pattern information. Some degree of “spillover” would be unavoidable for both road density and distance to nearest road analyses. That is, the road density moving window or the expanding window used to detect the nearest road would invariably include pixels of other land-cover types. Thus, the road density associated with a given pixel of forest, for example, would include roads on nearby grasslands; the nearest road to that same pixel of forest might be one on adjacent grasslands.

Considering terrestrial systems all together, it would be possible to determine either of these two metrics with all non-road land-cover types treated equally. This would remove the “spillover” issue. This is essentially the outcome of the road density indicator evaluated on a watershed basis (see below), and it has been done for the distance to nearest metric by both Riitters and Wickham (2003) and the MNF report discussed above (Fleming et al. 2004). Note that Riitters and Wickham compared the metric for all land cover taken together to that of just forest pixels; they found little differences (see figure below), however, there may be regional variability leading to differences in the indicator values.

To evaluate road density from a freshwater perspective, it would be logical to use watersheds as the analysis unit. Ecologically, this makes sense because, by definition, all points within a watershed are nominally connected hydrologically to the stream(s) in the watershed. And, while a road in a neighboring watershed might cause noise and other problems for organisms in the subject watershed, the effects of roads that have direct impacts on streams (e.g., barriers to movement, sedimentation, runoff, pollution, etc.) will be largely captured. (Note that it would be possible to measure road density with a moving window and then summarize by watershed, however, this would invariably lead to roads outside of the watershed influencing the assigned road density—that is there would be “spillover” reflected in the results (see above).)

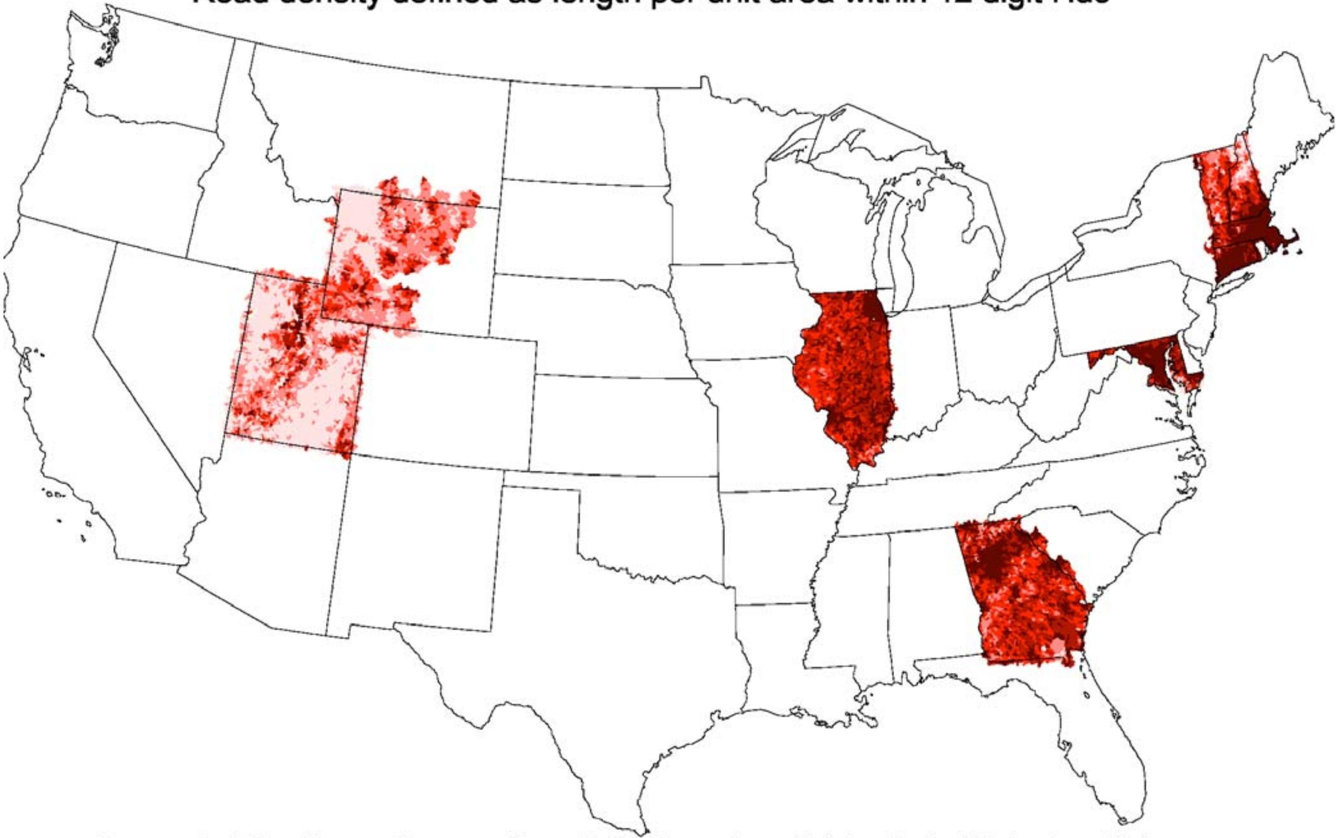
The issue of “spillover” discussed above would also be an issue if one wanted to estimate the distance to nearest road on a watershed basis, assuming that one were most concerned about road effects that operated within instead of across watersheds (e.g., increased sedimentation, and not “remoteness”). That is, portions of a watershed would undoubtedly have their nearest road in a neighboring watershed. Again, this does not eliminate the value of the indicator, but it may not be the most desirable method of analysis.

Road Density & Distance to Nearest Road: A terrestrial perspective

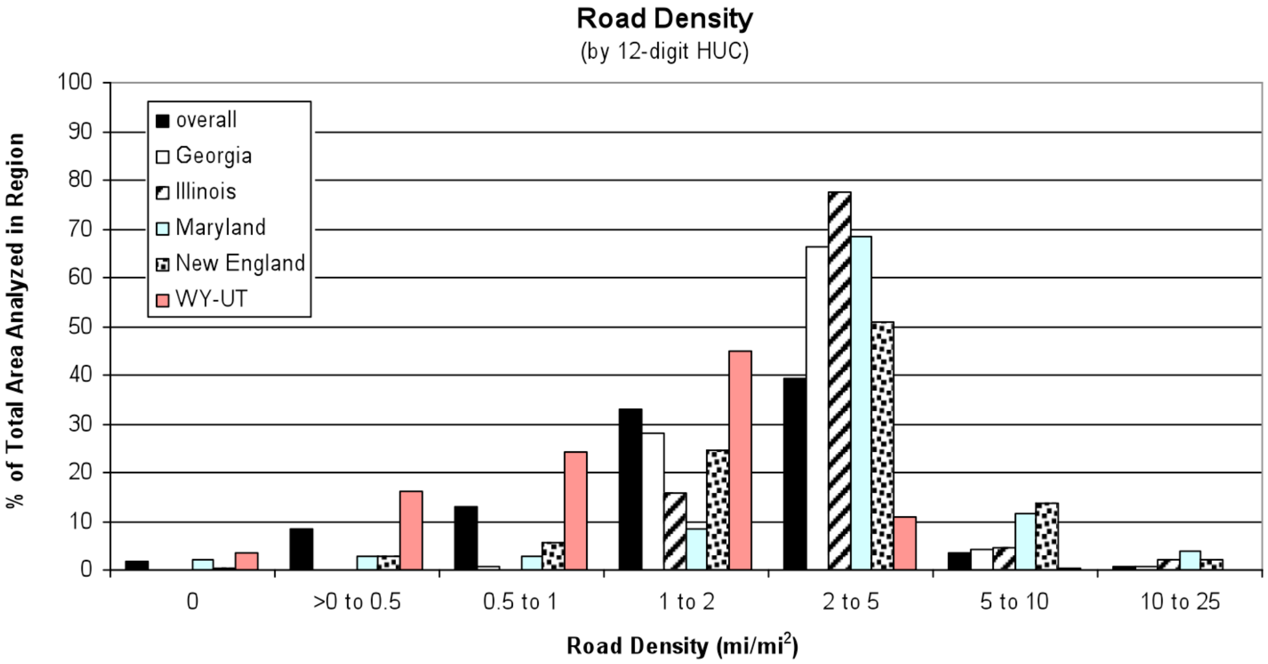
Road density was analyzed by analysts from the U.S. Forest Service and the U.S. EPA on a watershed basis. The unit of analysis was 12-digit HUCs, which get their name from the hierarchical Hydrologic Unit Codes used to describe them; this is the finest resolution HUC available. Measuring road density by watershed was not necessarily ideal from a terrestrial perspective, however, they are reasonably sized analysis units: 12-digit HUCs represent sub-watersheds ranging in area from 0.05 to 1700 mi^2, with a mean in all regions of about 30 mi^2. The distinct advantage to utilizing this analysis for terrestrial discussions is that there is a strong interest in using a watershed-based road density indicator for freshwater systems (see below).

At the moment, 12-digit HUC delineations are available for only a part of the country: Georgia, Illinois, parts of New England, Utah, and the western part of Wyoming. Road density is displayed in the following map and graph:

Road density defined as length per unit area within 12 digit Huc

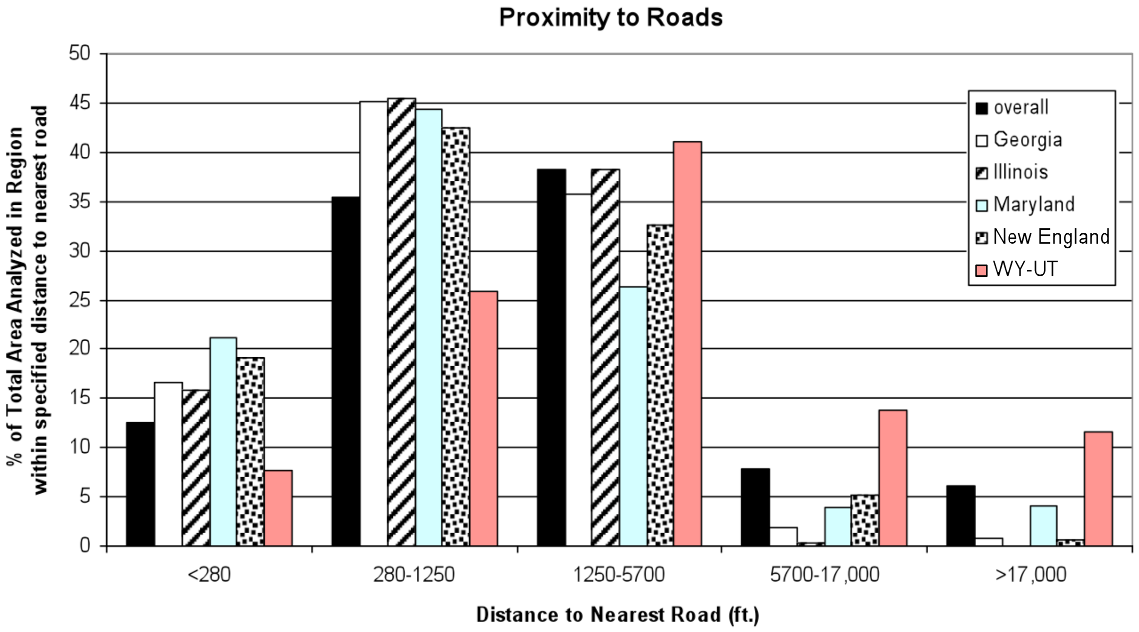


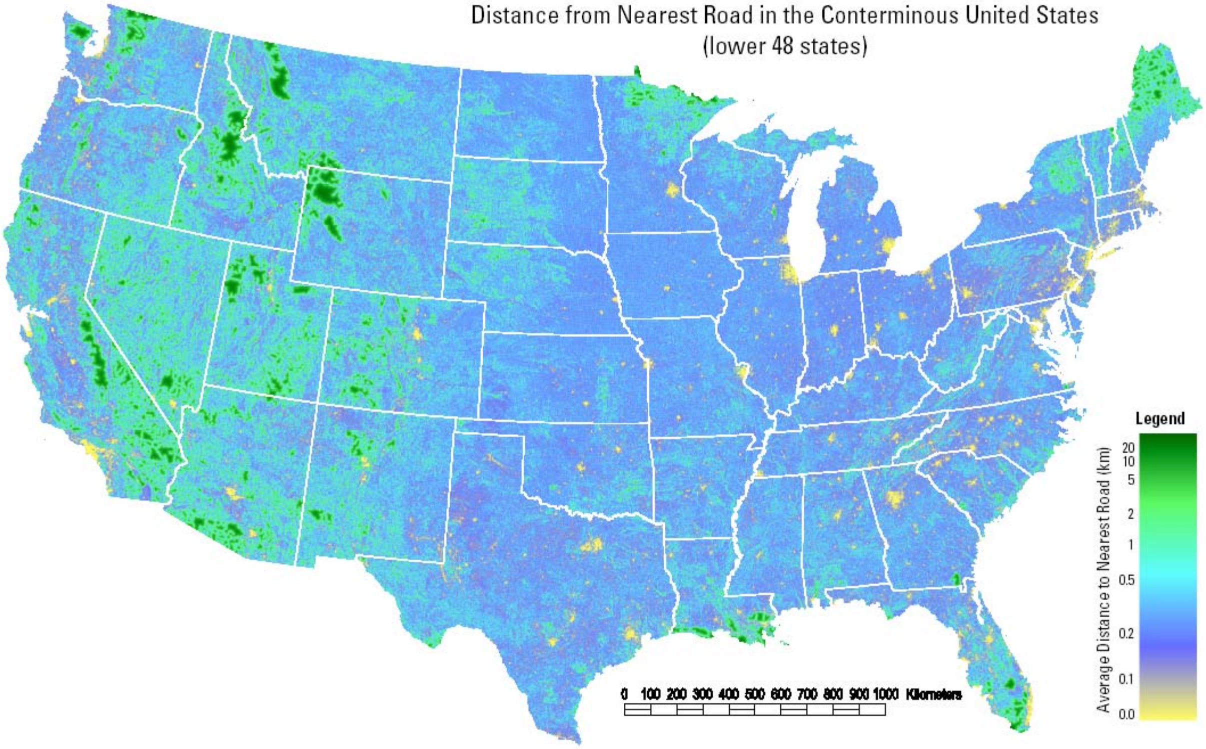
Legend. The five colors go from light (low density) to dark (high density). Each map displays five quantiles, for example the lowest quantile contains the 20% of the Hucs that have the lowest values.



This analysis of road density matches up fairly well with that for the Monongahela study area presented in the section that discusses scale above. Overall, variations in road density are apparent from region-to-region, as is apparent from the map of road densities.

Distance to the nearest road was computed for the same areas as in the road density analysis. Even though this was done on a watershed-basis, the data can be evaluated simply on a regional basis (i.e., the proximity to roads in one region can be compared to another, as well as to the road densities for that region). The following graph is a summary of these data.





The above map (provide by Ray Watts of USGS) is for distance to nearest road for the same regions shown in the road density map above.

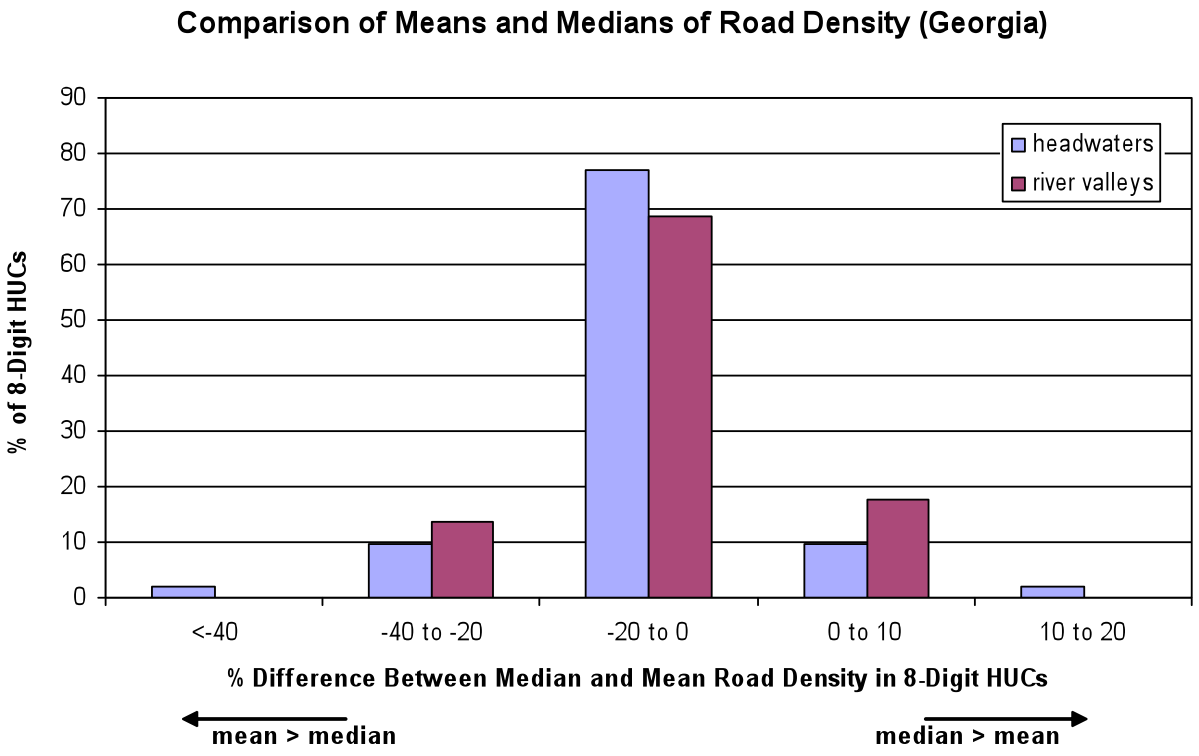
Several observations are possible from comparing the graphs and maps:

- There is clear inter-region variability in both metrics.
- The Wyoming-Utah region has the largest percentage of its area with low road density, and it also has the largest percentage of its area in the two highest proximity classes (5700-17,000 and >17,000 ft.).
- Regions with the most area in the highest road density classes (Maryland and New England, along with Georgia and Illinois that also have similar percentages in the highest road density class) have similar distributions on the proximity to roads graph—there are certainly some differences, although they do not necessarily fit a pattern that is easily explained.
- Qualitatively, areas on the density map that have low road density are also highlighted on the distance to nearest road map as being the most isolated from roads.

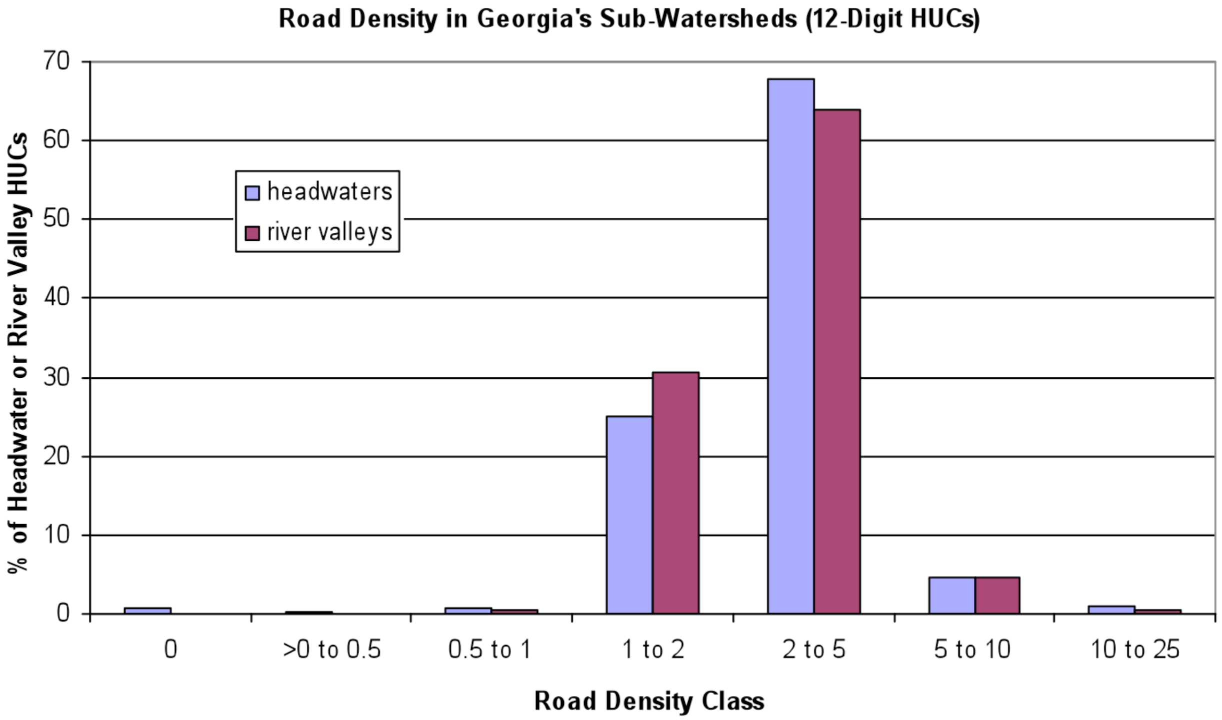
Road Density: A freshwater perspective

This section could be updated with similar data from Utah
As described in the section above, there is clear inter-region variability in road density. This was presented above as the % of total region area, but not in a way necessary to show inter-basin variability.

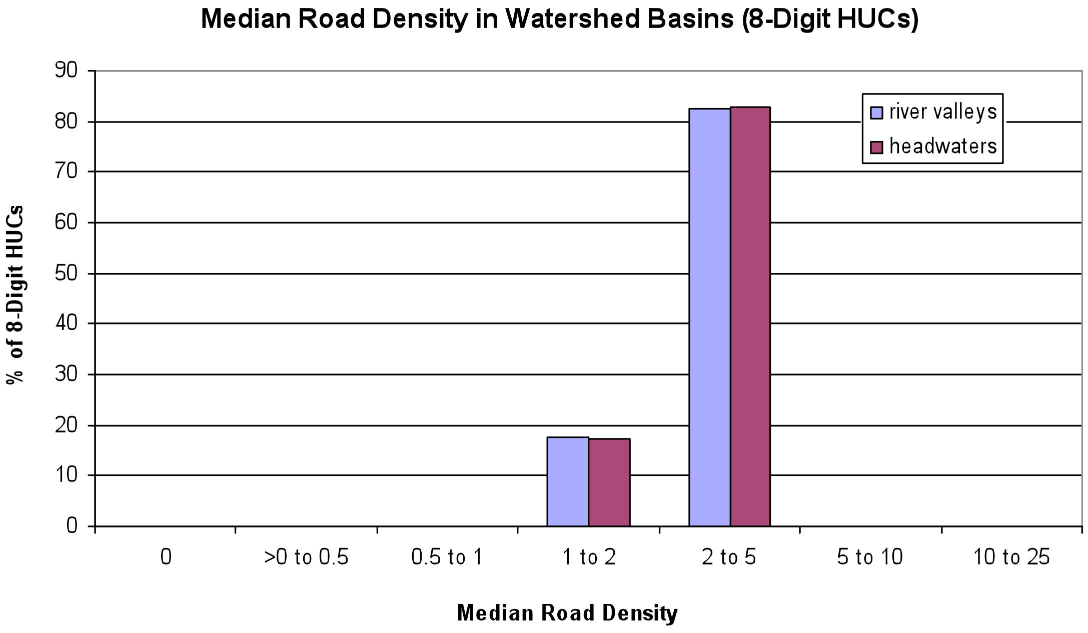
Sub-watersheds (i.e., HUC-12 regions) were deliberately chosen as the analysis unit so that the variability between sub-watersheds could be measured for larger basins (e.g., HUC-8 regions). That is, it was important to understand if roads are spread evenly across these larger basins, or if instead they are concentrated in only some of the sub-watersheds. The idea here is that if a basin has one or more sub-basins with very high road densities even though the overall basin's average road density is modest, then the fact that there are some pockets of high road density should be reflected in the indicator value. Thus, the median value of HUC-12 road density was taken for each basin (8-digit HUCs). The following graph shows the difference between median and mean road density for 8-digit HUCs in Georgia. These data suggest that, for the available data, mean road densities are often greater than median road densities. Our sense is that this indicator should highlight cases in which there are just a few sub-watersheds with high road density in watershed. ***Thus, perhaps we need to revisit using medians in the calculation of this indicator.***


Comparison of Means and Medians of Road Density (Georgia)

The second important analysis step was to separate "headwater" HUCs from those that constitute the "river valleys." Tim Wade of the US EPA spent a large amount of time going through HUC-12s in Georgia one-by-one to decide its headwater/river valley classification (note that a headwater HUC was determined for this purpose by deciding if one or more streams originated in the HUC and no stream(s) flowed into it; the river valley HUCs were those that did not pass the test). The following graph contrasts the road density classes between headwater and river valley HUCs.



There appears to be very little difference between the road density in headwaters and river valley HUCs. Looking at this on a larger basin-scale, the following graph presents the median road density for 8-digit HUCs (i.e., each 8-digit HUC contains multiple 12-digit HUCs; the median of the individual 12-digit headwater or river valley HUCs is reported in the graph). Again, the differences are small. Note that the medians do not cover the same range in values on the x-axis, so there would be some additional variation if the classes providing more resolution were used; however, the differences are still small.



Again, the story is about the same—there is little difference between the median road density between river valleys and headwaters for Georgia when compared at the scale of 8-digit HUCs.

While our methodology for distinguishing headwaters from river valleys may need to be re-visited as well as the computation of the metric using medians (see above), a potentially larger issue is that we do not know much about the quality of coverage for the roads database across Georgia. If, for the sake of argument, the data shown do indeed reflect the actual conditions, then it would suggest that headwaters in Georgia are equally impacted by roads as river valleys. Because of the potential for downstream magnification of effects, a management goal might be to limit road density in headwaters…

This analysis is on-going. Namely, we need to classify 12-digit HUCs in a western region (e.g., Utah) in a similar fashion so that inter-region comparisons can be made.

Conclusions

- On a qualitative basis, maps of road density and distance to nearest road provide similar information about the pattern of roads on the landscape. Thus, if someone were presented a map of road density—like the one discussed above—it would appear that they would be able to infer a good deal about areas that are remote with respect to their proximity to roads.

- On a qualitative basis, the distributions of road density and proximity to roads agree with each other. It would appear that these indicators highlight remote areas similarly, but it is still not clear how strong the relationship between these is in the range where the distance to nearest is not large.

- Road density broken down by headwaters and river valleys is feasible, and a inter-regional comparison should improve our understanding of this indicator.

APPENDIX C: PROXIMITY OF CROPLANDS TO RESIDENCES: ADDITIONAL MATERIAL

Data

Preliminary data from the 2001 National Land Cover Data Set were used for the Hunterdon, NJ analyses. Location data on housing units for Hunterdon, NJ was provided by Rick Lathrop of Rutgers University. 2002 Land-cover data and household locations for the State of Maryland were from the Maryland Department of State Planning (http://www.mdp.state.md.us/landmapping.htm).

Spillover Effects, Etc.

Disincentives for Continued Farming—Development typically increases nearby land values and, in some states, the property taxes on farmland, thereby increasing financial incentives for farmers to sell their land to be used for further development. Commuter traffic on rural roads produces dangerous conflicts with slow-moving farm machinery (this can make it difficult for farmers to move equipment; residents can also complain about delays). Further, some development can diminish the aesthetic quality and recreation potential of formerly pastoral landscapes.

Low-density, scattered development requires a great deal of surface area for roads and infrastructure, thereby breaking up the farmland landscape. At some point—most likely long after spillover effects have restrained agricultural operations—the landscape will become too broken-up to support anything but the smallest farms, and the commercial infrastructure necessary to support agricultural operations will decline and eventually disappear. In addition, development often takes high-quality agricultural land out of production, either restricting agriculture or forcing it onto inherently less productive lands.

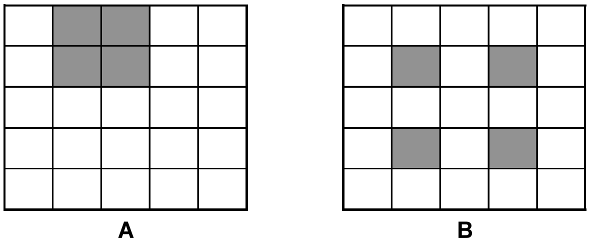
Spillover Effects—These effects occur when farmers apply pesticides, herbicides, fertilizers, or manure to the land; some portion of that which is applied may migrate to nearby developed lands. In addition, noise, dust, and odor that result from tilling the land and other agricultural operations are often unacceptable to people residing near farms. These spillover effects can lead to a negative reaction by residents that can potentially result in legal action against the farmers.

The likelihood that an agricultural operation will create spillover effects depends on the type of agriculture practiced. For example, high-intensity fruit and vegetable operations are more likely to have overspray, etc., than are less-intense operations, such as pasture grazing. Thus, the zone of influence, or the distance from an operation within which residential dwellers are likely to be affected, is larger for high-intensity operations.

The likelihood that spillover effects will trigger a negative response from residents most likely depends to some extent on how many residents are within the zone of influence—the chance of residents complaining is higher when there are multiple residences within the zone of influence as compared to a single residence. Although we have not been able to find evidence in support or in opposition to this idea in the literature, it makes sense intuitively.

Spatial Information Inherent to Indicator

This indicator concept is explained using the following sketch:



Both panels have the same number of developed pixels (4; gray) on a background of cropland (white). In panel A the development is clumped, whereas in B it is distributed across the landscape. If a moving window of 5 pixels on a side were used for Percent Development, the spatial arrangement of developed pixels would not be captured (i.e., panels A and B would both score 4 out of 25 pixels as developed). If we assume for the moment that a developed pixel is the same as a housing unit (an assumption that is shown below to be premature), then the proximity indicator would score these example landscapes very differently. The easiest way to see this is to imagine a buffer around each pixel of development; the indicator sums the cropland that remains outside of all buffers. For any given buffer size, there will be less cropland outside of the buffers in panel B compared to panel A. The recommended indicator that measures the proximity of croplands to residences, therefore, explicitly captures the spatial arrangement of development in the farmland landscape.

APPENDIX D: CHARACTERIZING LAND USE CHANGE

Sprawl[17] is a term often used to describe relatively low density suburban development, either at the suburban/rural fringe or in relatively isolated locations in otherwise undeveloped areas. It is perceived by many observers as being inefficient in use of land and resources, although it remains a popular development style.

Critics argue that the style of land conversion can sometimes be more important than the amount of the conversion. Organizations whose chief concerns involve urban planning goals may tend to emphasize qualitative attributes of "smart growth"—such as attractiveness, pedestrian-friendliness and compactness. Individuals, organizations (e.g., American Planning Association), and government bodies (e.g., planning commissions, city councils, county boards) may object to *sprawl* for a complex set of reasons. Development (e.g., *sprawl*) can be described in terms of area, land uses, and pattern (e.g., location within a region at one scale; spatial configuration of streets, lots, buildings at another scale). From the urban planning perspective—which, at its best, takes a holistic view of the world – concerns with *sprawl* include social impacts (e.g., human health, pedestrian safety, aesthetics, transportation convenience and accessibility, sense of community), economic impacts (e.g., fiscal implications of building and maintaining excess infrastructure, loss of farmland productivity), and ecosystem impacts (e.g., air and water quality, habitat integrity).

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[17] note that some content regarding definitions and reasons for caring about *sprawl* came from the website www.*sprawl*city.org—even though it has not been updated in several years, it is a useful resource.

APPENDIX E: AREA WITHIN HEINZ CENTER–DEFINED “URBAN & SUBURBAN AREAS”

Based on satellite-derived land-cover data from the 1992 National Land Cover Dataset (NLCD), just over 2% (41 million acres) of the area of the conterminous US is characterized by residential, commercial or transportation-related development.

This may seem like a negligible amount, but it understates the overall impact of human development on the landscape. For example, satellite-derived data generally cannot resolve fine-scale development, such as low-density housing—our prime reason for designing the land conversion indicator based on housing units rather than actual land conversions—and it misses other development that may be obscured from view by tree canopies. Perhaps more importantly, the 2% figure does not consider the amount of “natural” lands that are closely intermingled with development. That is, the ecological effects of land conversion extend beyond the building site, parking lot, or road right-of-way.

In fact, the Heinz Center’s definition of concentrated centers of development (i.e., urban and suburban areas; see below for more details) acknowledges that heavily developed landscapes include significant amounts of “natural” areas (note that an indicator slot remains to address “natural” areas in the urban/suburban landscape). The same type of intermingling occurs with more dispersed, low-density development, creating additional opportunities for ecological impacts.

For the 2002 *State of the Nation’s Ecosystems*, the Heinz Center defined a spatial unit termed the *urban and suburban area*. Urban and suburban areas were defined based on a number of decision rules using land-cover data from the 1992 NLCD, effectively creating areas covered by at least 50% developed pixels and at least 270 acres in size[18]. *What housing densities would we expect to find within urban and suburban areas?* We cannot answer this question directly, however, we can develop a comparison based on impervious surfaces.

For the 2008 *State of the Nation’s Ecosystems*, the Heinz Center defined urban and suburban landscapes as: the composition surrounding each pixel in a land-cover map was evaluated using two analysis windows (0.3 km on a side and 1 km on a side). For those windows that had at least 60% developed pixels in them, the center pixel was added to one of many urban-suburban landscape polygons. To be included in the urban and suburban landscapes, polygons had a minimal area of at least 270 acres (one-half square mile).

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[18] The NLCD divides the lower 48 states of the United States into several billion square pixels that are about 100 feet on a side. Analysis was of larger pixels (1000 ft on a side), each of which contains 100 of the smaller pixels. The first step was to classify any 1000-ft pixel as urban and suburban if a majority of the 100-ft pixels within it fell into one of the four “developed” land cover types available in the NLCD: low-intensity residential, high-intensity residential, commercial–industrial–transportation, or urban and recreational grasses. Very large aggregates of the 1000-ft pixels, which were found for metropolises such as New York City, were “smoothed” to some degree; that is, small clusters of “undeveloped land” pixels that were wholly included within a metropolis were subsumed in the urban and suburban areas. Other clusters of undeveloped-land pixels within an urban and suburban area, although connected to the perimeter by one or more pixels on a diagonal, were also included in the urban and suburban area. For clusters of developed-land pixels to be counted as urban/suburban in outlying areas, at least 13 of the 1000-ft pixels had to touch at their sides or corners for a minimum size of 270 acres.

There is effectively a minimum housing density that can be detected via satellite. In order for a pixel to be classified as one of the residential or commercial development classes, a certain level of impervious surfaces, among other factors, must be detected. The lowest-density class of development in the NLCD nominally has between 30% and 80% constructed materials (i.e., impervious surfaces) [19]. However, it takes about 3-7 residential units per acre to reach 40% imperviousness[20]. This implies that “urban suburban areas” have housing densities of about 3 houses per acre and higher; lower density housing would fall outside of their bounds.

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[19] Developed areas in the 1992 NLCD are characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc). Classes include: (21) **Low Intensity Residential** - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas. **(22) High Intensity Residential** - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover. **(23) Commercial/Industrial/Transportation** - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

[20] Chester, A. L. J. and C. J. Gibbons (1996). "Impervious surface coverage: the emergence of a key environmental indicator." Journal of the American Planning Association **62**(2): 243-258.

APPENDIX F: HEINZ CENTER–DEFINED FARMLAND LANDSCAPE

For the 2002 *State of the Nation's Ecosystems*, the Heinz Center developed two separate definitions for areas characterized by either development or agriculture. Each definition was applied resulting in numerous—in some cases, overlapping—polygons across the conterminous United States.

For the 2002 *State of the Nation's Ecosystems*, the Heinz Center created polygons across the country to define areas characterized by agriculture. Data were aggregated from the NLCD into squares 1 km on a side (approximately 1000 30-meter by 30-meter "pixels"). Each of these larger squares was analyzed to determine its land cover composition; 1-km squares in which more than 50% of the pixels were croplands were included within the "farmland landscape." In addition, a "buffer" equivalent to a single 1-km square was added to the edge of the farmland landscape defined above, in order to incorporate areas near those with significant concentrations of cropland. This set of "farmland landscape" squares was analyzed to determine its composition, using the land cover data for the underlying 30-meter pixels.

For the 2008 State of the Nation's Ecosystems, the Heinz Center defined farmland landscapes by evaluating the composition surrounding each pixel in a land-cover map using a square analysis window that was 3 km on a side. For those windows that had at least 10% cropland in them, the center pixel was preliminarily added to one of many farmland landscape polygons. To be included in the farmland landscape, polygons had a minimum area of at least 9 sq. km.

APPENDIX G: ECOLOGICAL IMPACTS OF DAMS AND DIVERSIONS—LITERATURE REVIEW[21]

> [Dams] are built to store water to compensate for fluctuations in river flow, thereby providing a measure of human control of water resources, or to raise the level of water upstream to either increase hydraulic head or enable diversion of water into a canal. The creation of storage and head allows dams to generate electricity; to supply water for agriculture, industries, and municipalities; to mitigate flooding; and to assist river navigation. However, the effectiveness of dam technology in delivering these services is hotly debated (Rosenberg et al. 2000).

Dams and water diversions often create large, widespread, pervasive and persistent departures from natural ecosystem processes and conditions, with serious consequences for aquatic biota at scales from local to global. Eighty-eight percent of the catchment area of large river systems (LRSs) globally (83% of their discharge, 59% of LRSs) is strongly or moderately affected by fragmentation by dams and water regulation, with remaining free-flowing systems mostly concentrated in the far north (Dynesius and Nilsson 1994; Nilsson et al. 2005). Medium-sized Scandinavian river systems show similar patterns. Large impoundments globally inundate an area comparable to California or France. As much as 6% of the world's runoff evaporates from irrigation diversions and reservoirs. (Dynesius and Nilsson 1994). More than 45,000 dams >15 m high are capable of impounding ~15% of the total annual river runoff globally (Nilsson et al. 2005). Another 800,000 small dams (Rosenberg et al. 2000, citing McCully 1996) may impound three to four times that volume (Rosenberg et al. 2000; St. Louis et al. 2000). It's estimated dams worldwide impound 10,000 km^3 of water, five times the volume of all the rivers in the world (Nilsson and Berggren 2000, citing Chao 1995), or enough to flood all the dry land in the world to a 10-cm depth (Nilsson and Berggren 2000, citing Pielou 1998). Reservoirs globally may trap >25% of sediment flux of all rivers (Vorosmarty and Sahagian 2000). Reservoirs may account for 7% or more of anthropogenic greenhouse-gas climate-warming potential over a 100-year timeframe, and even higher proportions over shorter terms (St. Louis et al. 2000). Large 20th-century increases in impounded volume globally may have significantly lessened sea-level rise that would otherwise have occurred with climate change; slowed 21st-century dam-building may become reflected in more rapid sea-level rise and associated effects (Vorosmarty and Sahagian 2000).

Effects of Dams and Impoundments on Riverine Ecosystems—"[A]lteration of flow regimes and associated severing of connectivity in the three spatial dimensions of riverine ecosystems perhaps are the most strikingly pervasive influence of humans on river landscapes world-wide" (Stanford et al. 1996). Irrigation consumes 64% of the Colorado River system' runoff and evaporation from reservoirs an additional 32%, leaving little to reach its mouth in the Gulf of California (Dynesius and Nilsson 1994).

Habitat fragmentation by dams has been shown to be a major cause of regional depletion of river faunas (reviewed in Dynesius and Nilsson 1994). Dams/diversions greatly alter conditions for riparian and aquatic organisms in several major ways: 1) reduction of habitat for organisms adapted to natural discharge and water-level regimes; 2) reduction of a stream's suitability as a

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[21] Prepared for the Heinz Center by Gary Carnefix, Carnefix Ecological Consulting; September 15, 2005.

corridor for movement and migration of organisms; and 3) modification of the riparian zone's function as a filter between upland and aquatic ecosystem components (Dynesius and Nilsson 1994). These may result from alteration of downstream continuity of water flow, thermal patterns, and carbon and nutrients (serial discontinuity sensu Stanford and Ward 2001); and include creation of novel habitats that serve as centers for the propagation and dispersal of invasive species, both in upstream reservoirs and in downstream reaches with altered flow, thermal, and chemical regimes. Flow variability is a crucial causative factor for habitat structure and function across spatial and temporal scales (Biggs et al. 2005), which dams/diversions often alter in highly significant ways. Habitat destruction and barriers to movement may have extinguished many riverine species over vast areas and threaten extinction of others through population fragmentation (Dynesius and Nilsson 1994).

Inundation, flow manipulation, and fragmentation can cause effects, often extensive and progressive, both upstream and downstream (Galay 1983; Petts and Greenwood 1985) including:

- alteration/destruction of terrestrial ecosystems (including natural riparian/floodplain/wetland areas and their dependent species) (Kingsford 2000; Kingsford and Auld 2005);
- elimination of turbulent reaches, disfavoring lotic biota; conditions favoring, and assisted spread of, exotic/invasive species; anoxia, greenhouse gas emission, sedimentation, and upsurge of nutrient and pollutant release in new reservoirs, including mobilization of methylmercury, with demonstrated human health implications for fish-consuming cultures due to bioaccumulation in predatory fish (Nilsson and Berggren 2000);
- increased or enhanced habitat for vectors (e.g., mosquitoes, snails) of human diseases (e.g., malaria, schistosomiasis) resulting in increased infections or epidemics (Keiser et al. 2005; Sow et al. 2002; Tetteh et al. 2004; Zheng et al. 2002);
- dewatering; concentration of pollutants in dewatered systems;
- substantial changes in land use patterns;
- hindered channel migration and development, with associated alteration of floodplain and riparian vegetation structure/ composition (Choi et al. 2005; Cluett 2005);
- altered flood timing and extent, wetland hydroperiodicity, nutrient and sediment loads, and overall productivity (Kingsford 2000; Kingsford and Auld 2005; Lu 2005);
- increased downstream erosion and/or aggradation (Petts and Greenwood 1985);
- upstream and/or downstream channel bed degradation (Choi et al. 2005; Galay 1983); altered aquatic-terrestrial-atmospheric-marine hydrologic cycling (e.g., drained wetlands evapotranspire less, increasing discharge variability);
- changed water table levels and surface-/groundwater flux, with conversion of riparian to
- upland vegetation communities (Nilsson and Berggren 2000 [citing Decamps 1988]);
- drained floodplain wetlands and reduced floodplain productivity;
- degradation of tidal/estuarine habitat dependent on freshwater inputs;
- decreased dynamism of deltas;
- and extensive modification of aquatic communities, including local extinctions and cascading threats to other species dependent on extirpated taxa (e.g., North American native freshwater mussels) (Dudgeon 2000; Nilsson and Berggren 2000; Nilsson et al. 2005; Postel 1998; Pringle et al. 2000; St. Louis et al. 2000; Vorosmarty and Sahagian 2000).

Among the important influences of dams on biodiversity is the “barrier effect”, i.e., prevention of migration throughout each aquatic system (Morita and Yokota 2002). Dams obstruct the dispersal and migration of organisms, fragmenting habitat and isolating populations, resulting in demographic, stochastic and genetic threats to persistence (Morita and Yokota 2002; Neraas and Spruell 2001; Pringle et al. 2000; Rieman and Mcintyre 1993). These and other effects have been directly linked to declines or loss of populations and entire species of freshwater fish (Dudgeon 2000; Morita and Yokota 2002; Nilsson and Berggren 2000; Nilsson et al. 2005; Postel 1998; Pringle et al. 2000), including Japanese white-spotted charr (Salvelinus leucomaenis, Morita and Yokota 2002); four Oklahoma (USA) prairie stream minnow species (Winston et al. 1991); and American shad *Alosa sapidissima,* Atlantic salmon *Salmo salar,* Atlantic tomcod *Microgadus tomcod,* Striped bass *Morone saxatilis*, sturgeon (species unknown); and dwarf wedgemussel *Alasmidonta heterodon* from a New Brunswick, Canada coastal river (Locke et al. 2003).

Human regulation of rivers by dams tends to "superimpose pervasive, continual perturbation on the natural disturbance regimes that sustain habitats and biotic communities", suppressing environmental heterogeneity and biodiversity and fundamentally reducing biotic productive capacity (Stanford and Ward 2001; Stanford et al. 1996). Discharge seasonality influences biota and land-water interactions, including seasonally inundated habitat for riparian/wetland terrestrial species (Dudgeon 2000). Flow regulation typically alters timing, annual flow amplitude, and baseflow variation, and changes other important biophysical patterns and attributes including temperature and mass transport (Stanford et al. 1996; Vorosmarty and Sahagian 2000). Flow regulation by dams may severely alter peak flows, over-bank flooding and baseflows, with important consequences to aquatic biota (e.g., Dudgeon 2000; Nilsson and Berggren 2000, citing Petts; 1984; USFWS 1994, Fig. 3, p. 9; Vorosmarty and Sahagian 2000). Because most river fauna are ectotherms whose growth and reproduction are temperature-dependent, temperature is a critical habitat attribute (Stanford et al. 1996).

Natural disturbance regimes such as periodic over-bank flooding produce a changing mosaic of channel, floodplain and vegetation structure, surface-/groundwater exchange and temperatures, creating a constantly shifting habitat template in floodplain reaches, which typically have the highest biodiversity and productivity and may often support core populations that are crucial to persistence of species that have metapopulation structure. “Resources needed by particular life history stages of organisms have discrete or ‘patchy’ distributions within this heterogeneous landscape” (Stanford et al. 1996). Natural biota of rivers display life history adaptations for survival within the range of environmental variation that characterizes a particular river (Dudgeon 2000; Stanford et al. 1996). If this range changes, organisms must locally adapt to the new regime or be extirpated; human-mediated environmental change can be so rapid and so severe as to exceed the ability of biota to adapt (Pringle et al. 2000; Stanford et al. 1996). With stream regulation: 1) habitat diversity is substantially reduced; 2) access to critical seasonally inundated floodplain habitat may be lost; 3) native biodiversity decreases and non-native species proliferate; and 4) biophysical conditions reset predictably in relation to influences of tributaries and as distance downstream from the dam increases (Dudgeon 2000; Stanford et al. 1996).

Changes in natural hydrologic and disturbance regimes by dams may be greater threats to aquatic biota in some cases than the physical barriers to movement that they represent. For example, construction and operation of Libby Dam on the Kootenai River in Montana probably did not restrict the range of endangered white sturgeon *(Acipenser transmontanus)*, whose upstream movement is probably limited by Kootenai Falls 50 km downstream (although anecdotal records suggest a second population of white sturgeon might historically have occurred upstream of the falls). Changes in the natural hydrograph caused by dam operation, however, changed temperature and discharge conditions (likely migration and spawning cues) during the natural spawning period, changed habitat configuration, reduced overall biological productivity and drastically reduced flushing peak flows, degrading cobble spawning and incubation substrates and off-channel habitats by embedding them with fine sediments. These factors are considered the primary cause of a near-complete lack of natural recruitment since 1974, the year before the dam became fully operational (Usfws (U.S. Fish and Wildlife Service) 1994).

Although the scientific literature is limited, dams have important ecological impacts beyond the strictly aquatic environment on amphibian and terrestrial biota and habitats. For example, Lind (2005) found significant associations of a variety of dam-related variables (e.g. presence, number, size, distance upstream, reservoir area, and interactions with precipitation) with foothill yellow-legged frog *(Rana boylii)* status, which she attributed primarily to departures from natural hydrologic regimes rather than direct effects as physical barriers to movement. Dams also inundate terrestrial species habitat, and large dams may create islands from formerly connected habitat, disrupting gene flow among newly isolated populations and causing large changes in species richness/community structure and trophic interactions (Diamond 2001; Wu et al. 2003).

***Indicators of River Alteration by Dams*—**Few attempts to characterize fragmentation of aquatic systems by dams/diversions at landscape scales exist. Exceptions are Dynesius and Nilsson's (1994) classification of large river systems in the northern third of the globe and medium-size Scandinavian river systems; and Nilsson et al.'s (2005) expansion of that work to all large river systems globally. These analyses developed separate classifications of 1) main-channel fragmentation by dams/diversions; 2) tributary fragmentation by dams/diversions; and 3) flow regulation for whole-river-system catchments (drainage basins); then combined them into a single classification for the whole river system of "strongly affected", "moderately affected" or "not affected" by fragmentation and flow regulation. The main-channel fragmentation classification was proportional (classes of proportion of longest undammed main-channel segment relative to entire main-channel length). The tributary classification was categorical, based on presence/absence of dams in the largest and in remaining tributary catchments. The flow regulation classification was based on combined reservoir "live" storage (excluding unregulated residual volume), diversions into/out of the catchment and irrigation consumption as a proportion of total catchment discharge before any human manipulation (Dynesius and Nilsson 1994; Nilsson et al. 2005).

This literature review is in support of a "proof of concept" derivation of two metrics of prevalence of dams/diversions across the United States (Carnefix and Frissell 2005) -- which were hypothesized to be potentially useful indicators of the influence of dams at landscape scales -- as one element of an effort by The Heinz Center and the Landscape Pattern Task Group to characterize patterns of anthropogenic influence and ecological integrity at landscape scales. The primary focus of our effort – reflected in the two indicators developed -- was on the fragmentation of stream network connectivity by dams and impoundments as physical barriers to movement of organisms, in conjunction with other ecological impacts of dams/diversions (e.g., flow-regime alteration) reviewed above.

The two indicators developed vary by scale (Biggs et al. 2005; Frissell et al. 1986; Petts 2000) and in how connectivity is interpreted. One indicator focuses on the coarse-scale spatial context of geographic analysis units (i.e., 12-digit Hydrologic Unit Codes) relative to dams that are on the stream network, but beyond the hydrologic unit boundary, as measured by the distance from the hydrologic unit's pourpoint (downstream outlet) to the first downstream dam encountered. The second metric focuses on internal connectivity at the subwatershed (12-digit HUC) scale (longest inter-connected stream network length as a proportion of total inter-connected stream network length within the subwatershed if there were no dams/diversions).

We opted to use a proportional fragmentation measure similar to Dynesius and Nilsson's (1994) main-channel classification only for the subwatershed internal connectivity indicator, where our metric was conceptually quite similar. There were two main reasons for this choice: 1) absolute connected available habitat size is an important factor for, e.g., large-bodied, far-ranging freshwater species such as sturgeons (family *Acipenseridae*) and paddlefishes (*Polyodontidae*); and 2) unlike the internal connectivity metric, our coarser-scale connectivity metric (distance to downstream dam) varied across four orders of magnitude, introducing factors of scale (see "1") not adequately captured by a proportional metric.

Both modeled (e.g., Jager et al. 2001; Morita and Yamamoto 2002; Morita and Yokota 2002) and empirical results (e.g., Morita and Yamamoto 2002; Morita and Yokota 2002) strongly support the "barrier effect" of dams fragmenting and thus reducing habitat available to a population/species, and thereby reducing probability of persistence. For example, length of time isolated and watershed area above dams were highly significant predictors of isolated white-spotted charr population persistence (Morita and Yokota 2002). Although it is commonly assumed that demographic or environmental stochasticity will generally extinguish small, isolated populations before genetic effects of isolation (e.g., Stacey and Taper 1992), an isolated population displaying a universal dorsal-fin deformity (Morita and Yamamoto 2000) and other empirical evidence of genetic deterioration in isolated *S. leucomaenis* populations (Morita and Yokota 2002) suggest this may not always be the case. Our indicators are intended to capture influence of such physical barrier effects in combination with effects of substantial habitat/ecosystem alteration associated with impoundments and flow regime changes described previously.

Because conservation measures have potential to conflict with economic interests, "private property rights", etc., managers, landowners, politicians and others often want to know what is a "minimum viable population" size, and how much habitat must be conserved to support it. Some studies have failed to find such a threshold, however; instead, extinction risk, as far as we can discern, increases continuously with increasing habitat reduction/fragmentation (e.g., Jager et al. 2001; Morita and Yokota 2002). It has also been noted (Smallwood et al. 1999) that the common practice of modeling 95 percent probability of persistence over a given period (often 100 years) to define a minimum viable population condemns one in twenty such populations/species to extinction within that timeframe.

Among the most difficult cases for freshwater species conservation is the threat posed to large-bodied, far-ranging freshwater species without obligate diadromous life histories, such as sturgeons and paddlefish, by river system fragmentation, flow regulation and habitat degradation by dams (e.g., Dudgeon 2000; Jager 2000; Jager et al. 2001; Pringle et al. 2000; Wei et al. 1997). Adults of these species have large home ranges, often obligate long-distance migrations, and they exist at low density, hence a large contiguous or connected habitat area is required to maintain a large population of individuals. Frequently, the critical impact may not be reduced habitat area per se, but blockage from (or destruction or attrition of) specific habitat elements with attributes critical to particular physiological needs or life history stages (e.g., foraging, spawning, incubation, juvenile rearing) (Dudgeon 2000; Northcote 1997; Pringle et al. 2000; Wei et al. 1997). For example, Chinese sturgeon *(A. sinensis)* migrated over 3000 km from the sea or brackish coastal waters (Xie 2003) to at least 16 historical spawning sites, distributed over at least 800 km of the Yangtze River. Gezhouba Dam blocked all but one major spawning site formed downstream of the dam (Xie 2003) from these populations in 1981, followed by sharp declines in *A. sinensis*, river sturgeon *(A. dabryanus)* and Chinese paddlefish *(Psephurus gladius)* (Wei et al. 1997). The reservoir now forming behind the Yangtze's Three Gorges dam threatens these populations further.

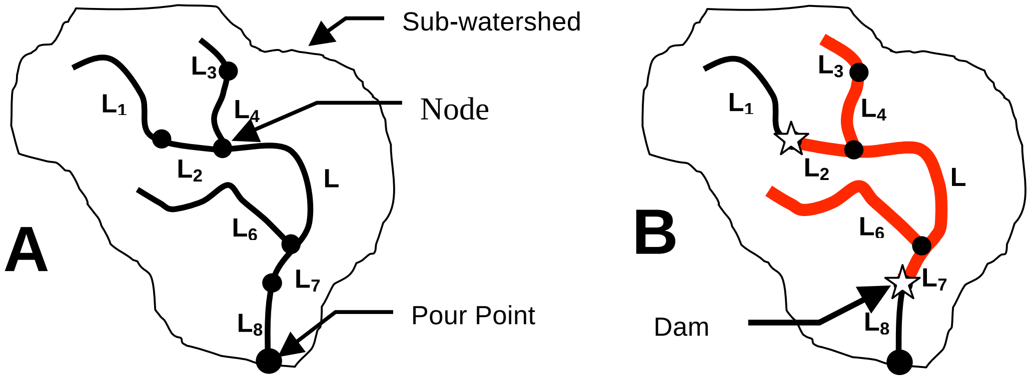
Specific estimates of minimum habitat area for viable populations are lacking for these taxa as well. Jager et al. (2001) modeled further damming of already-fragmented Snake River white sturgeon habitat from 200-km maximum simulated river reaches. Modeled 1000-year persistence probability declined exponentially from near 1.0 for existing strong populations with 200 km of otherwise suitable habitat (e.g., including spawning habitat and free-flowing refuge habitat from summer anoxic reservoir conditions) as further fragmentation by dams was simulated. The endangered Kootenai River white sturgeon population described previously has persisted approximately 10,000 years despite being naturally isolated and restricted between falls within a lake-river system length of roughly 300 km (Usfws (U.S. Fish and Wildlife Service) 1994), but is now in severe decline. In addition to the flow-alteration effects of dam operations already described, declining recruitment since at least the mid-1960s has been speculatively attributed in part to elimination of rearing areas for juveniles through diking of slough and marsh side-channel habitats and increased pollutants (e.g., copper, zinc) in the river that may have affected spawning success.

For our derivation of metrics of dam pervasiveness described above (Carnefix and Frissell 2005), we desired to set the break dividing the category of longest distance-to-downstream-dam values from shorter-distance categories such that this highest (i.e., least-impacted) category could be reasonably assumed adequate for aquatic species such as sturgeon and paddlefish. As the preceding review suggests, white sturgeon is the only such species for which anything resembling a quantitative estimate of minimum habitat requirements is available. These studies suggest that, in reasonably intact habitat containing all required elements for all life-history stages, 200 – 300 km of connected river-lake habitat might be sufficient for high probability of persistence over a timeframe of 100 – 10,000 years, at least for one sturgeon species. However, when other stressors occur in conjunction with reduced habitat size due to fragmentation by dams (as is nearly always the case), this amount of connected habitat may no longer adequately provide all elements required for long-term persistence. Such additional stressors may include 1) reduction/elimination of habitat suitability due to flow alteration, e.g., conversion of suitable Snake River white sturgeon lotic habitat to unsuitable lentic reservoir habitat (Jager 2000; Jager et al. 2001) (reservoirs replace very substantial proportions of free-flowing river habitat in numerous river systems); 2) ecosystem changes caused by flow alteration or other factors which favor introduced competitors/predators, which may displace native species from previously suitable habitat; 3) elimination, degradation or disconnection of seasonal/peripheral habitats such as floodplain side-channels or springbrooks, which may provide crucial resources to one or more life history stages or strategies (e.g. Kootenai River white sturgeon) (USFWS 1994); 4) loss of genetic resources in the form of local adaptations to novel or marginal environmental conditions, which may be important reservoirs of resilience/resistance for species/population persistence (Scudder 1989); etc. On this basis and to include a conservative factor of safety (including allowing for headwater portions of stream networks that may not provide suitable habitat for this group of species), we set our category break at 500 km, reasoning that river networks with at least this much interconnected main-channel length would likely provide at least islands of habitat of sufficient size, quality and complexity to support long-term persistence of even such species as sturgeon and paddlefish that are native to them.

APPENDIX H: INTERNAL CONNECTIVITY INDICATOR

This indicator was not selected as the main recommendation of the Task Group. However, components of it were incorporated within the Task Group's recommended indicator.

Determined on a subwatershed (12-digit HUC[22]) basis, the metric (see Figure 32 and Appendix I) is the longest interconnected stream network within the subwatershed (N*) divided by the stream network's total interconnected length within the subwatershed if there were no dams/diversions (N_t). If there are no dams (or diversions) within a subwatershed, then $N_t = N^*$ and the metric has a value of 1; if one or more dams are in the subwatershed, then the numerator of the indicator takes on the length of the longest network (aggregated lengths of interconnected stream segments) within the subwatershed that is dam-free (see Figure 33 for several examples), and the indicator takes on a value from 0 to less than 1.



$$\boxed{Index = \frac{N^*}{N_t}}$$

$$\boxed{N_t = L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8}$$

$$\boxed{N^* = L_2 + L_3 + L_4 + L_5 + L_6 + L_7}$$

Figure 32: Schematic description of Internal Connectivity index. (A) Given a stream network represented by segments L1 through L8, the overall network length is Nt. (B) To compute the index, the unobstructed network length (N*) is divided by the total network length (Nt) in a given subwatershed. In this case, the location of the two dams causes the longest unobstructed network to begin upstream from the pour point, rather than at the pour point. "Unobstructed" means the absence of one or more dams or diversions. Dams are shown with white stars.

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[22] "HUC" stands for "hydrologic unit code," and is used to catalog watersheds, or portions thereof, hydrographically across the landscape. Often "HUC" is used as a noun synonymously with watershed.

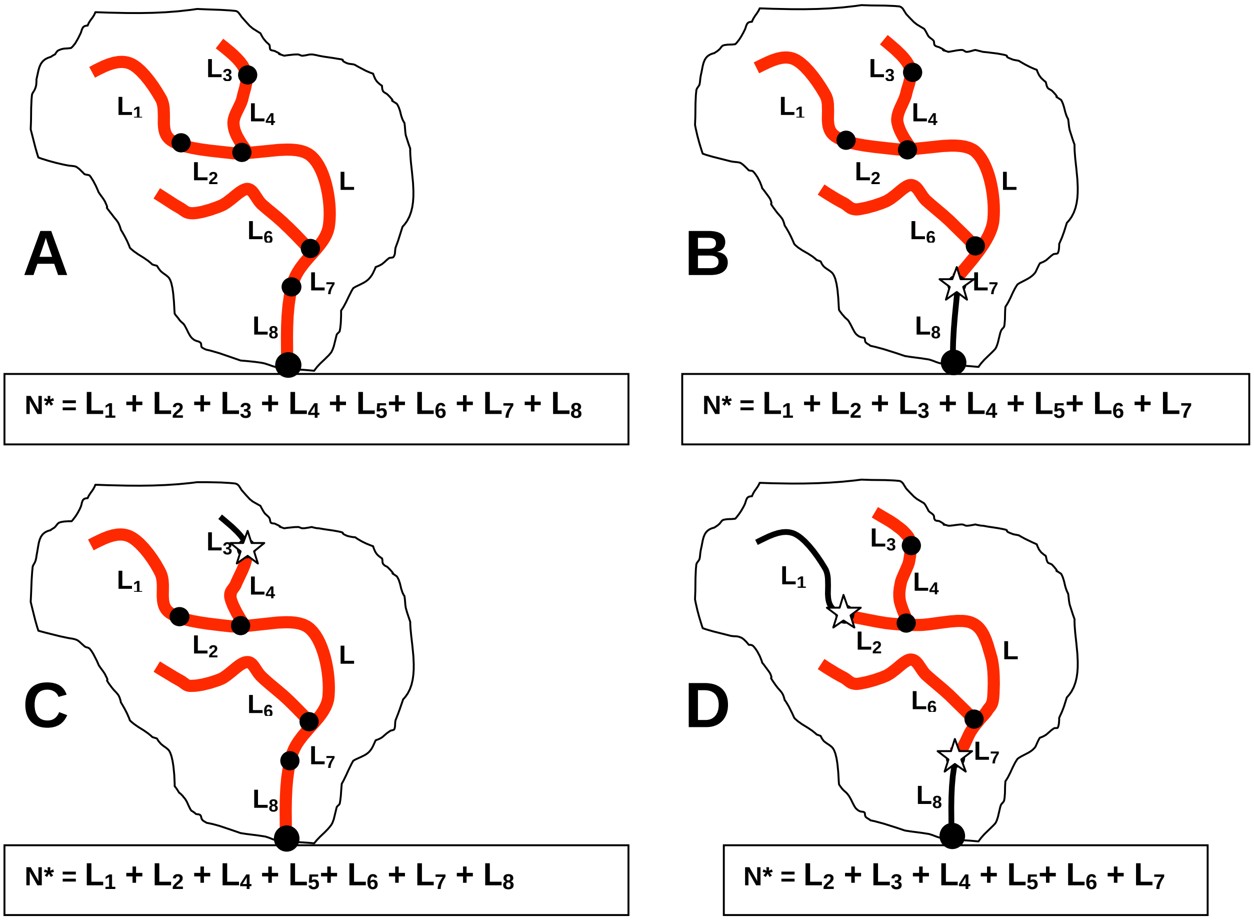

Figure 33: Schematic showing examples of the unobstructed network length (N*; shown with a heavy line) for several different dam scenarios within the same subwatershed (please refer to Figure 1 for definitions and explanation of symbols). Scenario A, with no dams, would have the highest index value (1.0). Scenarios B and C would have similar values, and Scenario D would have the lowest index value.

Sample results from the case study testing for the internal connectivity indicator are shown in Figure 34 (the regions correspond to those shown in Figure 18). Overall, nearly 80% of the tested subwatersheds had index values of 1.0, indicating the absence of dams. The Sweetwater Creek watershed in Georgia had the highest proportion of subwatersheds with index values below 1.0, although only a total of 8 subwatersheds were tested in this area. All of these data should, in general, be interpreted with some caution given that the sampling was designed to show a range of conditions within and among contiguous areas, rather than a rigorous statistical sample across the larger region or the country.

It is our understanding that there are no established cut-offs that can be attributed to a qualitative assessment of internal connectivity (e.g., values below 0.6 do not necessarily indicate impaired ecological function), however the indicator has intuitive meaning: on a 0–1 scale, it describes how much of the subwatershed’s stream network is unobstructed by dams.

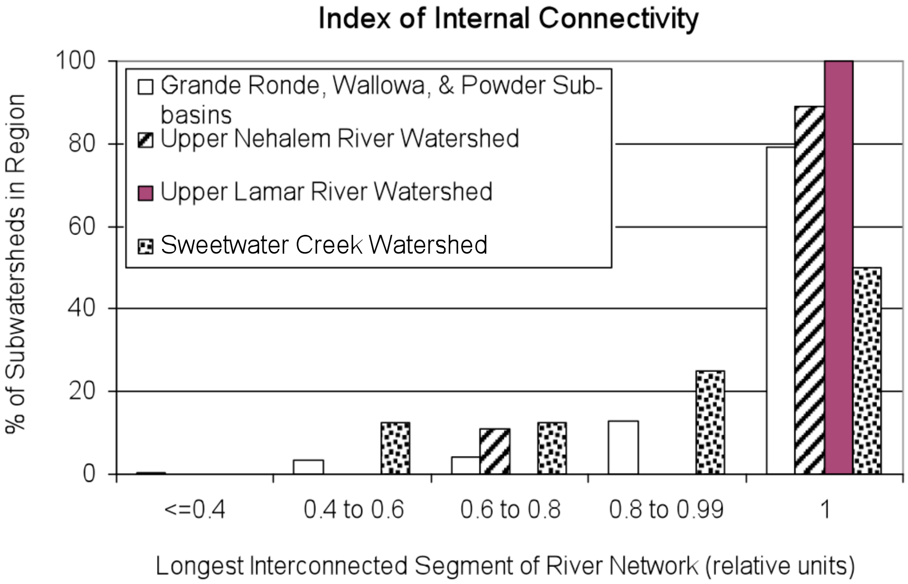

Figure 34: Results for the "index of internal connectivity" from the four study areas. Index values were determined by dividing the longest dam-free portion of the river network by the total length of the river network in a subwatershed (i.e., 12-digit HUC).

APPENDIX I: FRESHWATER IN-STREAM CONNECTIVITY INDICATOR—METHODS

Full details of this analysis can be found in (Carnefix and Frissell 2005), which is available upon request from the Heinz Center.

Data Sources: Geographic Information Systems (GIS) datasets were obtained from two sources: Streamnet (http://www.streamnet.org/online-data/GISData.html) and the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (http://www.icbemp.gov/). All but one dam location dataset examined had numerous location errors/imprecision relative to stream hydrography datasets. Due to problems encountered using the Streamnet hydrography (see Carnefix 2005), as well as improving accessibility, utility and standardization of the National Hydrography Dataset (NHD), all Phase 2 work was done using the 1:100,000-scale NHD "medium-resolution" hydrography (however, for visual clarity, some broad-scale figures display ICBEMP's lower-resolution 1:250,000-scale hydrography to reduce visual "clutter").

Similarly, the National Inventory of Dams (NID) dataset was adopted as the standard for the analysis where comparison with other available dams data indicated it was the most complete and reliable (i.e., that it included some dams omitted from other datasets; and that where other datasets included dams not in NID, they were generally "off-network" dams that would be ignored with our protocols). This was not consistently the case in the inland Pacific Northwest, however, where preliminary work demonstrated that ICBEMP/Streamnet datasets contained some dams that substantially influenced the results for our indicators, but were not in the NID data. Therefore, all four available dams datasets (NID, Streamnet and the two ICBEMP coverages) were used for the regional analysis of the four contiguous sub-basins in the Snake R. basin.

Data manipulation/structuring for derivation of dams metrics**—**Datasets were downloaded from the Internet in Arc Interchange Format (.e00), as ArcGIS shapefiles or as ArcGIS geodatabases, with the exception of the Streamnet dams point event table (dBase file, .dbf). All .e00 datasets were imported to ArcGIS 9.0 using the ArcMap import tool. All datasets for a given analysis (geographic area) were re-projected as necessary to the same geographic coordinate system and projection. Relevant datasets were added to an ArcMap Project for processing and derivation of each metric for each geographic summary unit (sub-basin or watershed). For the Snake R. basin regional analysis and mapping, sub-basin data were then combined in a new project.

Due in part to major complications resulting from minute, unexplained gaps in the Streamnet hydrography, segments to be aggregated were multiple-selected, then summed in ArcGIS using the hydrography attribute table's "Statistics" option. For long mainstem sections (e.g., to first dam downstream of Yellowstone R.), segments were selected by querying the hydrography attribute table by stream name (e.g., "Yellowstone River"), then visually examining and manually selecting/de-selecting segments as required. Within single subwatersheds, multiple stream segments to be aggregated were generally selected manually (i.e., by mouse click). Where dams subdivided individual stream segments of the hydrography, stream lengths were measured manually by tracing them with the ArcGIS measuring tool. Results were exported to an Excel spreadsheet for summarization and calculation of the indicators, re-imported to ArcGIS as dBase (.dbf) tables and then joined to the hydrologic unit attribute tables for map display.

Calculation of distance to downstream dam—The distance to downstream dam metric (dwndiskm) for each subwatershed was derived as follows. Starting from the pourpoint of the most downstream subwatershed in the particular sub-basin/watershed analysis unit, the distance to the first downstream dam was calculated by selecting and summing stream segments and/or measuring with the ArcGIS measuring tool as described above. For subsequent upstream subwatersheds without intervening dams, the dwndiskm value of the adjacent downstream subwatershed was added to the mainstem length through the downstream subwatershed to the upstream subwatershed's pourpoint to obtain the dwndiskm value of the upstream subwatershed. Where a dam intervened in the downstream subwatershed, the distance from it to the upstream subwatershed's pourpoint was calculated or directly measured as previously described. Then the process continued as described here for any subsequent upstream subwatersheds.

Proportion of longest unobstructed network to total interconnected length—For subwatersheds lacking any dams on the connected stream network within the subwatershed, this indicator's value was 1.0 by definition. If any dam(s) occurred on the stream network within a subwatershed, lengths of all interconnected stream segments within the subwatershed downstream of the first dam (= Network 1) were summed in ArcGIS and entered in the spreadsheet (unless a different network was clearly longest, in which case that network length was calculated instead). This was repeated upstream until the longest interconnected network unobstructed by dams within the watershed was clearly identified and its length determined. The total length of all stream segments within the subwatershed that would be interconnected if no dams were present, and the proportion that the longest network represents of this total, were similarly calculated in the spreadsheet, then imported to ArcGIS for map display.

Appendix J: SERGoM dataset

The Data

The data used for this indicator come from the SERGoM dataset created by David M. Theobald, Department of Human Dimensions of Natural Resources and Natural Resource Ecology Lab Colorado State University, Fort Collins, CO. Further, Theobald performed the specific manipulations described below under contract to the Heinz Center.

Data Description:

The SERGoM methodology used to generate historical and current estimates of housing density (as well as a forecasting model) is described in detail by Theobald (2001; 2005). Essentially, these data are generated from the US Census Bureau's SF1 dataset. Theobald compiled the number of housing units and population for each block in 2000 using the geography or polygon boundary for each census block. The blocks were then converted to 1 ha cells (100 m x 100 m) using the centroid method. That is, the center of each raster cell was intersected with the block polygons and the value associated with the block at the centroid is attributed to the whole raster cell. Note that by using the centroid method, there is no systematic bias towards larger polygon sizes (as there is with a dominant cell method).

An aggregation of block polygons and attributes of the number of housing units built by decade at the block-group level were used to estimate the historical number of housing units in each block. An operating assumption in estimating historical housing units is that they have not declined over time, so that the number of housing units in any past decade (back to 1940) did not exceed the number of units in any subsequent decade (up to 2000). Reservoirs, lakes, and wide rivers that were identified as "water blocks" were removed, so that no housing units were attributed to these undevelopable areas. Also, each block has three measures of area: total area, area of land, and area of water. Housing density was computed using area of land within each block, which accounts for small ponds and lakes that are not large or distinct enough to warrant their own block.

In addition to eliminating locations where lakes/reservoirs and rivers would preclude housing units, Theobald also refined the geometry of blocks to remove portions that were undevelopable because of ownership or land use constraints. That is, roughly ¼ of the US is in public land (upwards of ½ of the West) and private housing units are not allowed on these lands. The operating assumption here that housing units do not occur on publicly owned lands (e.g., national parks, forests, state wildlife areas, etc.). Also, some privately-owned lands have conservation easements placed on them also can preclude development. The portions of blocks that overlapped with public (and other non-developable lands) were deleted to create a modified or refined block. All housing units associated with each block were then assumed to be located in the refined (developable) blocks. Data on land ownership was obtained from the Conservation Biology Institute's PAD v4 database (http://www.consbio.org/cbi/projects/PAD/index.htm), which is largely a consolidation of USGS Gap stewardship maps.

The density of major roads (interstates, state highways, county roads) was computed to provide a more accurate allocation of the location of housing units within a block. In a previous SERGoM model (v1), housing units were spread evenly throughout the refined blocks. In the version of

SERGoM used for this study (v2), housing units were disproportionately weighted to areas with higher road density. In small blocks (~<40 acres) that typically occur in urban and suburban settings there is fairly uniform road density, so the allocation of housing units is roughly evenly distributed. In more rural areas where refined blocks can range from 100s to sometimes 1000s of acres, allocating housing units closer to roads follows the assumption that houses tend to be relatively close (~within a mile or so) of main roads for access purposes.

Data Manipulation: Data were estimated for each grid cell (100 m x 100 m) across the lower 48 states for two time periods: 1990 and 2000. The number of houses added between the two census time points were reported based on the housing density for the grid cell in 1990. Data were then summarized regionally and nationally.

Data Quality/Caveats: Information are not currently available on the accuracy of the SERGoM model. As mentioned in the figure legend on the indicator page, the reported data exclude about 25% of the households built on land having a pre-existing (1990) density of 1 house per acre or less. The SERGoM model computes housing densities for all grid cells that have not been excluded (e.g., they have a large water body on them or have a protection status that would prevent home building). Thus, all of these grid cells ultimately have a non-zero housing density. Further work is needed to determine whether or not the very low pre-existing housing densities are accurate. We decided that it would have been premature to include those data at this time.

The SERGoM model had high accuracy overall for 1990 (urban = 93.0%, exurban = 91.2%, and rural = 99.0%) and reasonably high accuracy for 2000 (urban = 84.2%, exurban = 79.4%, and rural = 99.1%).—see Theobald (2005) for more details.

Data Availability: Data were provided by D. Theobald under contract. Contact the Heinz Center or D. Theobald to receive this dataset.

GLOSSARY

Ecosystems are interdependent webs of organisms and the physically defined environments they exist in. Ecosystems may range in scale from the size of a pond or smaller, to a broad region such as the Gulf of Maine. For this report, the nation's lands and waters are divided into six broad ecosystem types (coasts and oceans, farmlands, forests, fresh waters, grasslands and shrublands, and urban and suburban landscapes) based on dominant vegetation or physical and chemical characteristics.

Coasts and oceans include all waters in the U.S. Economic Exclusion Zone (EEZ), which extends 200 miles from the coastline (an area of over 3 million square miles. This indicator focuses on the area covered by coastal wetlands, coral reefs, and shellfish and seagrass beds. Note that the map shows ocean depth to distinguish shallow coastal waters from the deep ocean; the area of the EEZ changes only when territory is acquired or international law changes.

"Core forest" is defined as small parcels (~1/4 acre), or pixels, of forest—defined by land cover data—surrounded by a specific amount of forest and other "natural" land cover.

"Core grassland" is defined as small parcels (~1/4 acre), or pixels, of grassland—defined by land cover data—surrounded by a specific amount of forest and other "natural" land cover.

"Core shrubland" is defined as small parcels (~1/4 acre), or pixels, of grassland—defined by land cover data—surrounded by a specific amount of forest and other "natural" land cover.

"Core Natural" is a landscape pattern attributed to a single small parcel (~1/4 acre) of "natural" land cover whose surrounding 240 acres is composed solely of other "natural" parcels.

Farmlands are represented in this indicator by the total area of cropland, including pasture and acreage in set-aside programs such as the Conservation Reserve Program (this land is not permanently taken out of production).

"Farmland landscape" includes both croplands and intermingled and adjacent forests, grasslands and shrublands, wetlands, and developed areas. The Heinz Center defined farmland landscapes by evaluating the composition surrounding each pixel in a land-cover map using a square analysis window that was 3 km on a side. For those windows that had at least 10% cropland in them, the center pixel was preliminarily added to one of many farmland landscape polygons. To be included in the farmland landscape, polygons had a minimum area of at least 9 sq. km.

Forests are lands—at least one acre in size—that have more than 10% tree cover.

Freshwater ecosystems include wetlands, ponds, lakes, reservoirs, streams, and rivers (the length of small, medium, and large streams and rivers is included). Wetlands occur in many ecosystem types, so their area is often also counted as part of the area of forests, grassland and shrublands, farmlands, and urban and suburban areas

Grasslands and shrublands include lands ranging from coastal meadows in the Southeast to tundra in Alaska. Those in the West are often called rangelands because of their historic association with cattle grazing.

"Natural" lands include forests, grasslands, shrublands, wetlands, other fresh waters, and coastal waters. In general, the term "natural" lands is applied to those lands that are not highly managed. However, a range of management conditions may be included in the “natural” category because classification of “natural” lands relies primarily on satellite-based land cover maps, not on land use. For example, forests with similar land cover patterns are considered equally “natural,” regardless of their management regimes.

“Natural” Landscape Pattern is attributed to a small parcel of “natural” land cover whose surrounding 240 acres has more than 80% other “natural” parcels with a mix of cropland and development, but with neither of these exceeding 10%.

“Natural”/Cropland is a landscape pattern attributed to a small parcel of “natural” land cover whose surrounding 240 acres has more than 80% other “natural” parcels with more than 10% cropland but less than 10% development mixed in.

“Natural”/Cropland/Developed is a landscape pattern attributed to a small parcel of “natural” land whose surrounding 240 acres has more than 60% other “natural” parcels with more than 10% development and more than 10% cropland mixed in.

“Natural”/Developed is a landscape pattern attributed to a small parcel of “natural” land whose surrounding 240 acres has more than 80% other “natural” parcels with more than 10% development but less than 10% cropland mixed in.

“Non-natural” is simply a small parcel whose land cover is either cropland or development—its surroundings are not evaluated.

“Some Natural” is a landscape pattern attributed to a small parcel of “natural” land whose surrounding 240 acres has at 60% or less other “natural” parcels, with the remainder made up of development and/or cropland.

Urban and suburban landscapes are defined in this report as land that is surrounded by sufficient amounts of developed land based on satellite imagery. Parcels of land were classified as urban–suburban landscapes if a square area (270 acres) surrounding the parcel was composed of at least 60% developed land cover. Because this definition is based on actual land cover, rather than on an indirect estimate of developed land area based on population density, the satellite-based definition of urban and suburban landscapes appears to be more appropriate for this report and is used as the basis for the urban and suburban indicators

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