ERDC/CERL TR-06-36

US Army Corps
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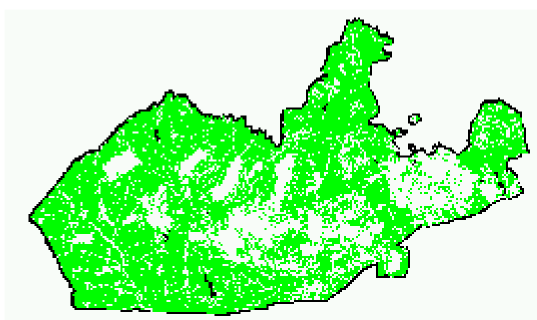
Engineer Research and
Development Center

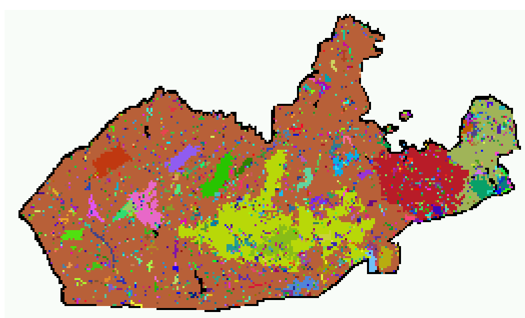
Habitat Fragmentation Handbook for Installation Planners

Status and Options

Robert C. Lozar, editor
Charles Ehlschlaeger, James Westervelt, Harold Balbach,
H. Resit Akçakaya, Tom Hoctor, Crystal Goodison,
William W. Hargrove, Forrest M. Hoffman, Winifred Rose,
and Robert C. Lozar

December 2006





Construction Engineering
Research Laboratory

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Robert C. Lozar, editor
PERTAN Group, 44 E. Main St., Suite 502, Champaign, IL 61820

Charles Ehlschlaeger
Western Illinois University, 306C Tillman Hall, Macomb, IL 61455

James Westervelt and Harold Balbach
Construction Engineering Research Laboratory, PO Box 9005, Champaign, IL 61826-9005

H. Resit Akçakaya
Applied Biomathematics, Setauket, NY 11733

Tom Hoctor and Crystal Goodison
University of Florida, Gainesville, FL 32611

William W. Hargrove and Forrest M. Hoffman
Oak Ridge National Laboratory, One Bethel Valley Road, Oak Ridge, TN 37831

Winifred Rose
PERTAN Group, 44 E. Main St., Suite 502, Champaign, IL 61820

Final Report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit #CNN-T602FF

ABSTRACT: The primary objective of this work is to provide military installation planners with a sourcebook on the state of the art in how to analyze the probability and risks of habitat fragmentation for animal Threatened and Endangered Species (TES). The document provides a review of habitat fragmentation issues, focusing on those of highest concern to Army Military Installation Land Managers. It has been designed to capture information developed during the 4-year ERDC research project called: Quantify Effects of Fragmentation and Approaches to Mitigate. Major components include:

- TES habitat background survey
- Army TES Life histories and potential supporting data types
- Description of major Fragmentation initiatives
- Survey of the major Fragmentation modeling techniques
- Evaluation of Data Quality
- Potential inputs for a long term TES monitoring capability
- Recommendations for future directions.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

Système International d'Unités ("International System of Measurement"), commonly known as the "metric system."

Preface

This report is a deliverable product under direct-allotted Department of the Army project A896, "Base Facilities Environmental Quality"; Work Unit number CNN-T602FF, "Quantify Effects of Fragmentation and Approaches to Mitigate" and is part of a Science and Technology Objective. This work was funded by Headquarters, U.S. Army Corps of Engineers. The technical monitor was Scott Belfit, DAIM-ED.

The work was performed under the direction of the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL), U.S. Army Engineer Research and Development Center (ERDC). The CERL Principal Investigator was James Westervelt. Part of this work was done by Robert C. Lozar under contract with the PERTAN Group, 44 E. Main Street, Suite 502, Champaign, IL 61820; contract number W9132T-05-D-001, Task Order 0002, "Fragmantation Analysis Guide for Installation Planners." Additional work was accomplished by Charles Ehlschlager, Western Illinois University; James Westervelt and Harold Balbach, ERDC-CERL; H. Resit Akçakaya, Applied Biomathematics; Tom Hoctor and Crystal Goodison, University of Florida; William W. Hargrove and Forrest M. Hoffman, Oak Ridge National Laboratory; and Winifred Rose, PERTAN Group. Alan B. Anderson was Chief, CEERD-CN-N, and Dr. John T. Bandy was Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-CV-T. The Director of CERL was Dr. Ilker R. Adiguzel.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Background

Army lands must, first and foremost, support troop training to optimize a soldier's battlefield success and survivability. Therefore, soldiers must "train as we fight" and continually train to keep skills fresh. However, the optimal use of military lands to fulfill this goal is threatened by federal, state, and local laws that require managing the same lands to simultaneously meet other objectives. And, urban developments near installations, many of which were originally established in very isolated areas, destroy areas with habitat suitable for supporting Threatened and Endangered Species (TES) populations. Military installation planners need a way to improve their ability to identify appropriate land near an installation that, if purchased, will relieve threats of TES habitat fragmentation and thereby sustain future training and testing requirements and opportunities.

Army training lands were often originally placed in remote areas where potential conflicts with surrounding land use could easily be avoided. Installation property boundaries delineated where people were not allowed to trespass, but the actual result of military impacts (in the form of dust, smoke, noise, and eventually radio interference) were known to extend well beyond the property lines. Property boundaries did not influence the use of landscapes by plants and animals. Habitat patterns and mosaics continued to evolve through natural succession and disturbance processes, including fire, disease, and insect invasions. Although the occupation of a specific piece of land by plant and animal species would change over time, the overall texture of broad landscapes allowed populations of animals and plants to persist over tens of thousands of years in North American landscapes. In this ever-changing matrix of habitats, populations of plants and animals would be destroyed through various natural disasters, but could then easily repopulate areas progressing through the steps of habitat succession.

Human settlement patterns have dramatically changed the landscapes, but have done so in a way that the landscapes cannot and are not reclaimed by native species. This affects remaining natural areas in two important ways. First, the amount of natural habitat continues to shrink—decreasing the total carrying capacity for certain species. Smaller populations are more susceptible to total annihilation. Second, remaining habitat becomes disconnected. That is, animals and propagules from plants in the remaining good habitats cannot reach other populations through migration of animals or dispersion of plant pollens and seeds, resulting in the loss of genetic connectivity among islands of remaining habitat. This is habitat fragmentation. The different behaviors and habitat requirements of animals as well as the seed and pollen dispersal approaches for plants means that a given landscape may be fragmented for one organism but not for another, and the patterns of fragmentation can also be different. The loss of genetic connectivity will eventually result in the loss of genetic diversity within each sub-population, which makes the population more susceptible to disasters, thereby increasing the probability of local extinction.

The loss of habitat and connections among habitats to support genetic exchange increases the value of remaining habitat. Because military training generally is conducted in areas compatible with the habitats of threatened and endangered species, the value of military land for the conservation and preservation of these habitats continues to increase. In most cases, land on military installations is, by itself, insufficient for ensuring the long-term viability of populations. Areas of primary habitat for threatened species on installations must remain genetically connected and these areas must also remain connected to other off-installation areas. Habitats must not become so fragmented that small populations become isolated. The need to maintain connectedness has resulted in the loss of installation land to training.

While urban settlement patterns erode suitable habitat, resulting in the loss of on-installation training land, emerging weapon systems, tactics, and inter-service training requirements are requiring more extensive tracts of land to properly train the forces. The pressure to shrink training lands to accommodate the loss of habitat due to urbanization is met with the important need to increase training land to accommodate new requirements for inter-service training with modern and emerging weapon systems.

A number of tools are being used to address this double-pronged challenge of addressing training land encroachment and increased training land needs. Installations can work closely with local communities to help develop zoning and city/county master plans that are favorable to installation training sustainability. Working with state governments, legislation can be developed to help ensure that future growth occurs in a manner that sustains the viability of the installation as an economic engine. Smart land acquisition can help develop increased training and testing areas.

As the human settlement patterns in the United States have grown, the real ability of the government (state and federal) to forcibly acquire land to meet public needs has diminished. Although the legal ability to condemn land to allow the creation or expansion of an installation still exists, the political ramifications of such actions are so powerful that the Department of Defense (DoD) is extremely wary of land acquisitions in this manner. Instead, acquisition of private lands is generally accomplished through agreements with willing sellers. Such agreements take many forms and can involve many different private and governmental entities, agencies, individuals, clubs, and organizations. Each agreement can be unique and creative.

Objective

The objective of this research was to provide an initial source document that an installation land manager can reference as a state-of-the-art survey of TES habitat fragmentation studies and initiatives that have relevance to Army installation needs. It provides a review of habitat fragmentation issues, focusing on those of highest concern to Army Military Installation Land Managers, including approaches to identifying appropriate land for protection under the Army Compatible Use Buffer (ACUB) program.

Approach

To meet the above objective, researchers completed the following tasks:

- TES habitat background survey
- Army TES life histories and potential supporting data types
- Description of major fragmentation initiatives
- Survey of the major fragmentation modeling techniques
- Potential inputs for a long term TES monitoring capability
- Recommendations for future directions.

Scope

Although this volume was conceived to be a comprehensive source, is dwarfed by the plethora of excellent work already completed on this subject. The bibliographies in the Appendix (page 161) lend credence to this observation.

This study tends to focus on initiatives that have had more relevance and reference to military installations. Because of the nature of the issue of habitat fragmentation, this report leans heavily toward the discipline of regional-scale landscape ecology. Many fine studies are available for specific TES at a local level.

Finally, where possible, the relationship to specific needs of Army land managers has been emphasized. It is acknowledged that other groups and agencies might have different needs and a different focus.

Mode of Technology Transfer

An article describing this work has been published in the U.S. Army Installation Management Agency's *Public Works Digest,* Volume XVIII, No. 4, July/August 2006, p 19, "Endangered species land management guide available."

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

2 Fragmentation Overview

Author: Robert Lozar

Delineating the Issue of TES Habitat Fragmentation

Fragmentation Issues for the Army

One may rightly wonder why the military and the Department of the Army in particular are worried about questions of fragmentation and habitat conservation. Over the past decade such questions have become increasingly important at military installations throughout United States due to laws and regulations that require the military to manage its lands and resources, particularly those that support threatened and endangered species, by using the best scientific and technological methods available. Because natural species (particularly species of concern) cannot be administered solely on installation lands, the Army is wise to look beyond the boundaries of their lands, despite the fact that many installations are extremely large areas. The Endangered Species Act (ESA) of 1973 requires federal agencies to manage and protect and, in some cases, to provide for the recovery of species that have been identified at various levels of endangerment. For several years many installation staff members and scientists have worked hard to provide healthy habitats within federal lands, particularly in this case, within Army lands. Unfortunately, while the military was trying to provide an adequate response to the management of TES, native habitats of the endangered species have been disappearing at an alarming rate outside military installations. The trend is recognized at the highest levels of responsibility for military lands management:

> Military training lands that are threatened by encroachment from increasing development are coincidentally becoming the last best havens for at-risk species. Protecting lands that adjoin military lands with conservation easements and other protective measures is a win-win proposition that can provide increased protection to species before they

> are listed on the endangered species list while also reducing the management burden on military lands.[1]

The trend includes conversion of natural lands to agricultural uses (including forested lands used for commercial forestry) and to urban uses such as commercial and residential uses.[2] It became apparent that TES populations within installations were becoming isolated because habitat outside installation boundaries was being lost through land use change.[3] The Army's primary mission is to provide military readiness and military training at its installations. The investment in its lands and infrastructure was not originally intended to be a refuge for endangered species. Because of the scope of TES habitat extends beyond installation boundaries, to accomplish their major mission, military land managers would be wise to combine the limited resources set aside for TES habitat management with other agencies and private groups to ensure that the TES are managed to provide a logical unit of natural habitat that might extend beyond the boundaries of a single installation.

This chapter explores the background and emerging state of the art that will allow installation land managers to accomplish what might have seemed until recently an impossible task.

Environmental Science

Biodiversity Status

For many years it has been clear in the public perception that mass extinctions of species have occurred in the distant past. However, it is much less recognized that there are contemporary extinctions of species. Contemporary extinctions can cause subsequent changes in groups of species and their habitat, including the degraded of the environmental quality. Most people recognize that the tropical forests are important to the ecosystem of the earth and that these forests are experiencing some

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[1] Statement of Deputy Under Secretary of Defense (Installation and Environment) Raymond F. Dubois, Jr., before the House Armed Services Committee Subcommittee on Military Readiness, U.S. House of Representatives, March 14, 2002.

[2] Westervelt, J.D. 2004. *Approaches for Evaluating the Impact of Urban Encroachment on Installation Training Testing.* Technical Report, ERDC/CERL TR-04-4, ADA431772, March 2004. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL.

[3] Secretary of Defense Message. Public Affairs Guidance (PAG) for the 2003 Readiness and Range Preservation Initiative (RRPI) SECDEF. Washington DC//OASD-PA/DPO//, 132305Z Mar 03.

of the highest rates of species loss.[4] However, many people do not realize that, as functioning units, ecosystems in the United States are just as important and are being destroyed as quickly as those in the tropics. Examples are the freshwaters of California[5] or the old-growth forests in Northwest.[6]

Ecosystems

An ecosystem describes a community of all the species populations that occupy a given area plus its nonliving environment[7]. An ecosystem is a set of gradients of environmental characteristics that function as a unit. The ecosystem is best defined by characteristics of its core. As we move away from this core, the characteristics become less distinctive. Although it has been traditional to delineate ecosystems in the United States as polygons with distinctive edges separating one grouping from another,[8] such edges do not exist in nature. Because the common language represents ecosystems in this over-simplistic manner, the public can misunderstand the characteristics that really make a difference to the animals and plants that inhabit a region. It is difficult to portray the complexity of a natural ecosystem. With the advent of satellite imagery and the ability to manipulate detailed and complicated spatial data with Geographic Information Systems (GIS) analysis technology, these regions can be delineated objectively through their environmental forcing agents (i.e., the primary and basic reason a changes is set into motion). By defining a particular region as a set of variable characteristics with thresholds that allow a natural system to exist, we begin to represent an ecosystem as a continuum of natural forcing agents[9]. However such analyses present such multiplicity of possibilities that it is logical to summarize the gradients into a set of ecosystems that are sensibly identifiable and uniquely separated by thresholds. For most of this report the classical ecosystem characterizations will be used to simplify the discussion.

---

4 Myers, N. 1984. *The primary source: Tropical forests and our future,* W. W. Norton, New York. Myers, N. 1988. "Tropical forests and their species. Going, going..?" pages 28-35 in E.O. Wilson, editor, *Biodiversity*. National Academy Press. Washington, D.C. Wilson, E. O. 1988. *Biodiversity*. National Academy Press. Washington, DC.

5 Moyle, P. B. and J. E. Williams. 1990. "Biodiversity loss in the temperate zone: Decline of the native fish fauna of California." *Conservation Biology*. 4:475-484.

6 Norse, E. A. 1990. *Ancient forests of the Pacific Northwest*. The Wilderness Society and Island Press. Washington, DC.

7 Odum, E. P. 1971. *Fundamentals of Ecology*, Third Edition. Saunders. Philadelphia, PA.

8 Kucher, A. W. 1966 (revised 1985). *Potential Natural Vegetation* (map). U.S. Geological Survey. Reston, VA.

9 Hargrove, W. W. and F. M. Hoffman. April 2004. *A Flux Atlas for Representativeness and Statistical Extrapolation of the AmeriFlux Network.* http://geobabble.ornl.gov/flux-ecoregions/.

Examples of ecosystems include old-growth forests, wetlands, savannahs, or areas bordering rivers. In any definition of an ecosystem, it is useful to define areas on the basis of a hierarchical scheme.[10] By this method, the highest levels are the broadest definitions. Different sub-categories of the highest levels can be defined on the basis of additional environmental forcing factors/agents. By this means, we may eventually define an ecoregion that has a compelling correlation with the needs or habitat of a species or community of concern. That is, we can develop units appropriate for various uses, particularly for land management purposes.

A group that has been active in the area of defining ecosystems for management uses is The Nature Conservancy (TNC). TNC has developed a classification system that is defined by a combination of physical, habitat, vegetation, physiognomy, and species composition.[11] This system is of interest for military land management purposes because it is designed to reflect important concerns for conservation actions. It coordinates roughly with the military's need to define areas that can be actively managed, particularly for the purpose of endangered species conservation and recovery.

Ecosystems Status

A recent report by the U.S. Geological Survey (USGS) shows that across the United States almost all our ecosystems have been declining in terms of area and viability.[12] The level showing the greatest loss was called Critically Endangered (where there was identified a decline in the natural system greater than 98 percent). Those systems that showed a decline in the 85 to 98 percent range were termed Endangered. Threaten systems exhibited a degradation in the 70 to 84 percent range. In the United States, the areas of highest degree of decline were found to be in the South, the Northeast, the Midwest, and California, in that order. It should be noted that the military, particularly the Army, has a great number of installations in the South and California and to a lesser degree in the Northeast. There is a likely relationship between the decline of an ecosystem's health and land management cost to

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10 Anderson, J.R. 1970. "Major Land Uses. Scale 1:7,500,000," in *The National Atlas of the United States of America*. U.S. Geological Survey. Reston, VA.

11 Noss, R. F. 1987. "From plant communities to landscapes in conservation inventories: A look at The Nature Conservancy (USA)." *Biological Conservation*. 41:11-37.

12 Noss, R. F., Edward T. LaRoe, and J. Michael Scott. *Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation*. USGS Endangered Ecosystems. http://biology.usgs.gov/pubs/ecosys.htm.

the Department of Defense because DoD is managing large acreages of land within these most affected regions.

Ecosystem Loss

A loss of ecosystems can occur through land use conversion or degradation. Conversion is easy to measure: it is the change of one land use to another. For example, forestland may be converted to residential land use. Conversion implies a spatial extent; consequently, the statistics associated with conversion can be measured and manipulated with relative ease. Degradation of an ecosystem's quality is more difficult to quantify. For example, native grasses can be replaced with non-native invasive grasses. In this case, the ecosystem is still grassland. However, non-native grasses often have characteristics that are less desirable than those of the natives. For example, in the region of Dugway Proving Ground, Utah, large areas of the natural grasses have been replaced by invasive species, notably cheatgrass. In 1983, one cheatgrass fire burned 209,000 acres from Dugway to the Great Salt Lake because spring moisture had loaded the landscape with fuel. "It took off with strong wind and there was nothing we could do," said Dave Dalrymple, fire management coordinator for Utah's Division of Forestry. "We threw air tankers and everything we had at it. Natïve grasses stay green a long time, but cheatgrass is like gasoline after about June 15.[13] Cheatgrass is much more liable to catch fire and cause serious hot blazes on the installation. Of course, this temporarily puts military testing areas off limits (affecting Mission capability) and items burnt in the fire have to be replaced (affecting land management cost). Thus, the degradation type of ecosystem change can also have a direct effect on an installation's ability to carry out its mission.

Landscape Fragmentation

Habitats are not well-defined polygons with edges that are recognized by the plants and animals on the ground. Habitats are often fuzzily defined units running sinuously across the landscape. Units particularly vulnerable to fragmentation are those with shapes that have a distinct long axis; the possibility of having their short axis cut into two parts at its most limited point is great (Figure 2-1). Originally, habitat fragmentation was defined as the formation of isolated fragments from a formerly

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[13] "It Won't Rain All Summer," archived 05-01-2003; http://www.wildfirenews.com/archive/050103.shtml. April 15, from Washington, DC (about 3/4 of the way down this archive page).

continuous habitat.[14] Recently, it has taken on a meaning more appropriate to today's situation. Natural habitats are becoming so restricted that they are becoming more like islands of nature within an ocean of change. In fact, because military installations are managed to retain semi-natural areas to carry on their training missions, they can become examples of island habitats.

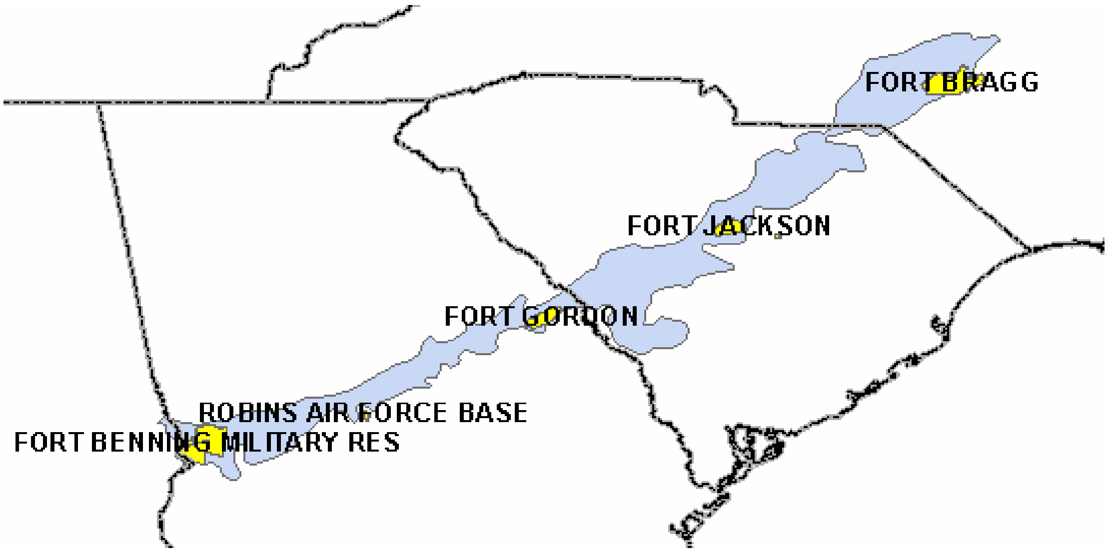

Figure 2-1. The Sandhills Ecoregion of the United States Southeast (blue) is particularly sensitive to fragmentation because of its long, sinuous form.

The area also contains a large number of military installations; many can be considered island habitats.

Endangered Species Act

Much of the Army's concern with fragmentation issues derives from its need to answer the requirements originating from the ESA of 1973. Factors in the determination of listing a species include "(A) the present or threatened destruction, modification, or curtailment of its habitat or range; (B) overutilization for commercial, recreational, scientific, or educational purposes; (C) disease or predation; (D) the inadequacy of existing regulatory mechanisms; (E) other natural or manmade factors affecting its continued existence."[15] The U.S. Fish and Wildlife Service uses a 12-point ranking system for determining listing priorities first by magnitude (high or moderate to low) and by immediacy (imminent or not imminent) of threat and secondarily by taxonomic distinctness (e.g., monotypic genus, species, or subspe-

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14 Harris, L.D. 1984. *Bottomland Hardwoods: Valuable, Vanishing, Vulnerable*. Florida Cooperative Extension Service, University of Florida, Gainesville.

15 Public Law 94-325 as amended, Sec. 4 (a), p. 4.

cies). A separate 18-point scale by degree of threat, recovery potential, taxonomic distinctness, and conflict with economic objectives is used to rank species for funding of recovery.[16]

Theoretical Basis for Fragmentation Studies

Regional fragmentation studies are derived from the discipline of conservation biology; specifically landscape ecology. They are based on the premise that ecological processes influence patterns on the landscape.[17] The assumption is that there is a correlation between spatial patterns and the ecological processes that have generated those patterns. Thus, identifying critical patterns in the ecological network also is a clue to identifying the forcing factor that created the pattern.

The most common tool used to measure patterns in the landscape is GIS. Within a GIS, specialized techniques have been developed to calculate measures that reflect the characteristics of the landscape patterns that can be discerned in the spatial information. The spatial information comes either from hand-derived datasets, such as street locations, or information generated automatically from remote sensing imagery, usually (at the landscape scale) satellite imagery. A competent spatial analyst will be able to formulate the calculations needed to characterize the landscape. However, several add-on software packages have been developed that provide sets of these calculations as an integral part of a GIS. The most notable of these is FRAGSTATS,[18] but many others have been built around this concept and are widely available. FRAGSTATS calculates a set of standard quanties (see the section titled Examples of Common Fragmentation Tools on page 22). More sophisticated add-on packages have built on the original FRAGSTATS idea and provide not only metrics about the landscape but also evaluations of the interrelationships of the landscape characteristics. Although there is a plethora of tools to analyze patterns, they have been criticized for the fact that the developers often do not understand the relationship of those patterns and their metrics to the viability of the species of concern.

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[16] Fay, J J., and W.L. Thomas. 1983. *Endangered and threatened species listing and recovery priority guidelines, Federal Register*. U.S. Fish and Wildlife Service 48 (184):43098-43105. Master, L.L. 1991. "Assessing threats and setting priorities for conservation." *Conservation Biology*. 5:559-563

[17] Forman, R.T.T. and M. Godron. 1986. *Landscape Ecology*. New York, John Wiley & Sons.

[18] McGarigal, L. and B.J. Marks. 1995. *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*. General Technical Report, U.S. Forest Service, Pacific Northwest Research Station, PNW-GTR-351.

It is also important to realize that with all the metrics available, it seems that the most critical factor is the quantity or density of roads in an area. This single characteristic underlies many other metrics because, for fragmentation, the placement of a road introduces the strong potential for additional and subsidiary land uses to be introduced, each of which further contributes to fragmentation.

> Effects of roads — what we call influence zones — extend tens of hundreds of meters from the roads themselves, altering habitats and water drainage patterns, disrupting wildlife movement, introducing exotic plant species, and increasing noise levels.
>
> The land development that follows roads out into rural areas usually leads to more roads, an expansion process that ends only at natural or legislated barriers. Unlike streams, which shape and are shaped by the land, roads are shaped by economic demands. The road network is designed to connect places efficiently in human terms. Roads often cross natural boundaries rather than going around, creating new patterns of movement within ecosystems. Though there is extensive research on how roads impact ecosystems at the site level, there is not much information about roads in relation to ecosystems at the regional level.[19]

The Infra Eco Network Europe (IENE), established in 1996, is a European network of authorities and experts involved in the phenomena of habitat fragmentation caused by the construction and use of linear transport infrastructure, especially motorways, railways, and canals (waterways). It succinctly states:[20]

> The consequence for wildlife of construction transport infrastructure include traffic mortality, habitat loss and degradation, pollution altered microclimate and hydrological conditions and increased human activity in the adjacent areas. All these cause considerable loss and disturbance of natural habitats. In addition, roads, railways, and waterways impose movement barriers on many animals, barriers that can isolate populations and lead to longterm population decline.

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19 Riitters, Kurt H., and James D. Wickham. 2003. "How Far to the Nearest Road?" *Ecology and the Environment,* 2003, 1(3):125–129.

20 http://www.iene.info/HFintro.htm

> Habitat Fragmentation, the splitting of natural habitats and ecosystems into smaller and more isolated patches, is recognized globally as one of the biggest threats to the conservation of biological biodiversity. Habitat fragmentation is mainly the result of different forms of landuse change. The construction and use of transport infrastructure is one of the major agents causing this change as well as creating barriers between habitat fragments.
>
> As transport systems have grown, their impact on fragmentation has become an increasing problem. The steady increase in animal casualties on roads and railways is a well-documented indicator of this problem.

It should be pointed out, however, that even this single important metric could suggest different significance. For example, the existence of a dirt road certainly imparts a different amount of impact compared to a state or federal highway. Also, some species have a greater reaction to the presence of roads than others do. For instance, for the endangered gopher tortoise that is endemic at many installations in the southeastern United States, any dirt road can be a major obstacle. The literature regularly cites “road kill” as the tortoises’ greatest threat. At the same installations, avian species such as the red-cockaded woodpecker (RCW, *Picoides borealis*) are little affected by the presence of small roads. So, simply on the basis of the means of mobility, different fragmentation metrics become important to different species of concern.

It should also be noted that the availability of landscape metrics allows a more objective evaluation of how well we are managing our landscapes. In addition to identifying habitats, landscape metrics can be used to monitor the extent to which landscape prescriptions have changed the face of the land and relate that back to the individual species of concern. By this method, we could measure the relative effectiveness of different actions in similar landscapes and show which has a better payback for management resources.

Defining the Landscape

Origins

We return now to the basic question: “Of all the metrics that can be generated, which are central to characterizing entities for landscape ecology for habitat protection purposes?” In a 1995 paper[21] Riitters et al. determined that, among those available, five measures exist that are useful in characterizing plant and species character and are not redundant of other measures: average perimeter-area ratio, average patch area, patch perimeter-area scaling (called the fractal dimension), image texture (called contagion index), and the number of attribute classes. To generate these values, the landscape must first be divided into three classes: patch, edge, and matrix. Patches are areas defined by a series of similar characteristics. The matrix portions are all those areas that are not patches based on the series of defined characteristics. And of course the edge is the region that occurs at the juncture of patch and matrix or patch and patch.

When delineating vegetation patches we have to be careful to ensure that there is a biological basis for the characteristics we’re choosing. The edges of patches are usually indistinct and grainy within the matrix of the region. The characteristics that define patches need to reflect the fact that nature exhibits very few definitive edges. Most of the time, when deriving patches from satellite images, we like to congregate areas of similar spectral response. This may indicate similar vegetation types. The big issue is, “Does the vegetation type reflect critical issues related to the habitat of the species with which we are concerned?” Another issue is, “Is there a fundamental characteristic of the patch that makes a difference in terms of landscape ecology to the particular species habitat and foraging characteristics?” Once again let us return to the issue of the gopher tortoise. A road may provide an edge of the tortoise’s patch, but presents no problem for the RCW.

Edges are locations where the qualities that define the core have decreased so much that the location can no longer be said to exhibit the character of the core members. The location of the boundary needs to reflect the sensitivity of the particular species of concern. The decrease in the core qualities at an edge is such that the species no longer consider this position part of their traditional environment, or patch.

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[21] Riitters, K. H., R. V. O'Neill, C. T. Hunsaker, J. D. Wickham, D. H. Yankee, S. P. Timmins, K. B. Jones, and B. L. Jackson. 1995. “A factor analysis of landscape pattern and structure metrics.” *Landscape Ecology* 10(1): 23-39.

The matrix is the area considered to not be appropriate for the habitat of the species under consideration. The matrix, although not habitat, is important in defining the negative characteristics of habitat, such as the amount of land that is not habitat or the distance between patches of suitable habitat.

Fragmentation Studies

Fragmentation studies are often limited to a specific habitat area and have largely focused on fragmentation of the remnant area that exists as a relic using island biogeography theory.[22] Other studies have focused on landscape units as a large matrix and the relationship of each unit within the matrix to others in terms of their cohesiveness (termed contagion).[23] In matrix fragmentation, the sizes and arrangement of the disturbed patches are of great interest because these metrics influence the cohesivenss of the habitat present.

Dealing With Small Patches

Although it is easier to deal with the concept of preserving small samples of various habitat types (often called the Living Museum[24]) this approach does not address the issue of fragmentation. These small islands of remnant ecosystems often do not provide adequate area for the species considered important. In fact, for many military installations, although the intent was not to preserve a Living Museum, they have found themselves in this position. Because of this, it has become apparent that it is necessary to look beyond the installation boundaries to be successful in providing protection to species that have a natural range well beyond those lands managed by the military. Successful conservation recognizes management of large interconnected land landscapes.[25]

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[22] MacArthur, R.H. and E. O. Wilson. 1967. *The Theory of Island Biogeography.* Princeton, Princeton University Press.

[23] Franklin, J.F. and R.T.T. Forman. 1987. "Creating landscape patterns by forest cutting: ecological consequences and principles." *Landscape Ecol*. 1:5-18.

[24] Noss, R. F., and L. D. Harris. 1986. "Nodes, networks, and MUMs: Preserving diversity at all scales." *Environmental Management* 10:299-309.

[25] Noss, R. F. 1983. "A regional landscape approach to maintain diversity." *BioScience* 33:700-706. Noss, R. F. 1992. "The Wildlands Project: Land conservation strategy." *Wild Earth* (Special Issue):10-25.

Ecosystem Conservation

Previously, most work has been targeted to be species specific, particularly in response to the Endangered Species Act. As a result, agencies have directed their efforts toward managing a single species at a time. However, it has been shown[26] that this approach is inefficient. As more and more evidence becomes available, the scientific community is beginning to realize that endangered species are a symptom of degraded or unhealthy ecosystems. On the other hand, if we deal with ecosystems as large units, we have the advantage of protecting diversity and addressing the primary cause of species decline—habitat destruction. In addition, this idea (also called the Ecosystem Conservation model) promotes management of a sensible natural unit. Compared to administration of land on a species-by-species basis, management of an entire natural system as a single unit is a cost-effective way to provide for many advantages all at once.

Community-level Conservation

The Nature Conservancy uses the community-level conservation approach. This strategy is one in which the community represents 85 to 90 percent of the species and includes many of the defining ecological processes. It has the advantage of representing most of the natural character of a region without the requirement of inventorying each species individually. TNC estimates that 85 to 90 percent of the species within a region can be served by using a "coarse filter"[27] approach to community conservation. The ecosystem approach (or coarse filter approach) used by TNC is at a level that can be fitted to deal directly with the concern at hand (often a species). One of the driving forces for the increasing interest in the community-level conservation concept results from the fact that the resources to support a species-by-species approach (as under the ESA) has been shown to have a very low efficiency and high cost relative to the successes that are produced.[28]

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[26] LaRoe, E. T. 1993. "Implementation of an ecosystem approach to endangered species conservation." *Endangered Species Update* 10 (3&4):3-12.

[27] Noss, R.F. 1987. "From plant communities to landscapes in conservation inventories: A look at The Nature Conservancy (USA)." *Biological Conservation* 41:11-37.

[28] Kohm, K. A., editor. 1991. *Balancing on the brink of extinction: The Endangered Species Act and Lessons for the Future.* Island Press, Washington, D. LaRoe, E. T. 1993. "Implementation of an ecosystem approach to endangered species conservation." *Endangered Species Update* 10 (3&4):3-12.

Several studies have shown the lack of success of the single-species conservation technique[29] due to the fact that its whole purpose is to react to the needs of only one entity without considering the larger picture. For example, more than $6 million has been spent during a recent 5-year period on Army research on RCW in the southeastern United States.[30] The RCW is important on a number of installations and will remain so until de-listed; installation populations are rapidly increasing and training restrictions have been reduced. In spite of this, the RCW remains one of the top concerns to installation land managers. Further, species of concern occasionally have conflicting environmental requirements. For example, the endangered species indigo snake (*Drymarchon Corais couperi*) in the southeast eats the eggs of the endangered RCW. So at an installation like Fort Stewart, GA, the question is, "Which of these two species do you choose to enhance if you are required to manage for the recovery of a single species?" Success for one species means a limitation on the other. As another example, the black-capped virio (BCV, *Vireo atricapilla)* at Fort Hood, TX, has the same locational requirements in its ecosystem as the golden-cheeked warbler (GCW, *Dendroica chrysoparia*), but each species' habitat requires a different stage in the natural plant succession cycle.[31] So when you manage the habitat for one species, you decrease resources for the population of the other species. Clearly these are conflicting requirements. Although the BCV/GCW conflict was addressed by establishing species-specific population goals for each species, and the ongoing training regime (especially man-made fire) is ensuring an adequate supply of both required habitat types, when you begin to manage for multiple TES, you are automatically moving toward the concept of a comprehensive, large-scale plan. On the other hand, if you manage by using the community-level approach, the benefit is to the entire sector of living organisms that make up the community as well as to the individual species. As a result, conflicts are resolved and habitat for

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[29] Hutto, R. L., S. Reel, and P. B. Landres. 1987. "A critical evaluation of the species approach to biological conservation." *Endangered Species Update* 4(12):1-4. Hunter, M. L. 1991. "Coping with ignorance: The coarse-filter strategy for maintaining biodiversity," pages 266-281 *in* K.A. Kohm, editor. *Balancing on the Brink of Extinction: The Endangered Species Act and Lessons for the Future.* Island Press, Washington, DC. Noss, R. F. 1991a. "From endangered species to biodiversity," pages 227-246 *in* K. A. Kohm, editor. *Balancing on the Brink of Extinction: The Endangered Species Act and Lessons for the Future.* Island Press, Washington, DC. Noss, R. F. and L. D. Harris. 1986. "Nodes, networks, and MUMs: Preserving diversity at all scales." *Environmental Management* 10:299-309. Scott, J. M., B. Csuti, J. D. Jacobi, and J. E. Estes. 1987. "Species richness: A geographic approach to protecting future biological diversity." *BioScience* 37:782-788.

[30] TES Research Program Review, ERDC/CERL, Champaign, IL, April 2002.

[31] U.S. Fish and Wildlife Service. 1996. "Black-Capped Vireo Population and Habitat Viability Assessment Report." Report of a workshop arranged by the U.S. Fish and Wildlife Service in partial fulfillment of U.S. National Biological Service Grant No. 80333-1423, Austin, Texas. Keddy-Hector, D. P. 1992. *Golden-cheeked Warbler (Dendroica chrysoparia) Recovery Plan*. U. S. Fish and Wildlife Service, Austin, Texas.

all community members is increased. As a corollary, it might also be that when you manage for a single species of concern, you may be affecting the habitat quality for another species that will then become endangered due to your management actions. This situation does not improve the military context, which is intended to fund the solution to problems, not support their creation. The other advantage of the community approach is that it also supports habitat improvement of commercially important species such as the deer. Commercially important species at installations can be used to generate income revenues through the selling of hunting licenses.

GAP Analysis

One of the earliest and best known examples of a comprehensive fragmentation analysis was the GAP Analysis. The National Biological Service supervises this analysis using habitat maps generated from satellite images, usually Landsat Thematic Mapper imagery as well as other ancillary data.[32] Although this national-level study has been continuing for several decades, it is being accomplished on a state-by-state basis as resources permit. Many of the maps and supporting data generated from this study are still not available to the public and each defined locale or category is classified by a particular characteristic that ends at the state boundaries (i.e., they do not flow sensibly into adjacent states). Further, the GAP Analysis identifies only particular units, not necessarily ecosystems, and occasionally does not cover the entire area of the state. For these reasons, the GAP Analysis may be of little use to installation land managers. Some of these issues are currently being addressed through an initiative call the ReGAP Analysis.[33] Despite its shortcomings, it should be pointed out that GAP Analysis is one of the very few national studies of natural area fragmentation in the United States.[34]

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[32] Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, J. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards, J. Ulliman, and R. G. Wright. 1993. “Gap analysis: A geographical approach to protection of biological diversity.” *Wildlife Monographs* 123:1-41.

[33] Development and Coordination of a Region-Wide Gap Analysis Program for Utah, Nevada, Colorado, Arizona and New Mexico: Utah Mapping Component http://fws-nmcfwru.nmsu.edu/SWREGAP/factsheet.htm.

[34] The USFS has an analysis at the national scale for forested lands. Though very useful, if a habitat does not relate to forested lands, it is of limited use. Riitters, K. H., J. D. Wickham, J. E. Vogelmann, and K. B. Jones. 2000. “National land-cover pattern data.” *Ecology*, 81(2): 604.

The Military

The Military and Fragmentation Issues

The environment within DoD to support and implement region-wide conservation techniques exists at the highest DoD levels:

> Ecosystem management is not only a smart way of doing business, it will blend multiple-use needs and provide a consistent framework to managing DoD installations, ensuring the integrity of the system remains intact (Implementation of Ecosystem Management in the DoD…)[35]

Regulations

Congressional directives, including and in particular the ESA and implementing regulations, require the Army to direct efforts toward the management, conservation, and recovery of threatened and endangered species. More specifically, the Army is required, among other things and on lands included in its jurisdiction, to identify threatened and endangered species and their habitats, determine population sizes, undertake no action that will negatively affect those species, and generally undertake actions that will support the survival of those species and lead to their removal from the threatened and endangered species list.

Army TES

Although the Department of the Army is responsible for maintaining the habitats of many species of various levels of concern, it has identified a specific set that are of the highest priority. Those species considered to be critical to the Army military installations are:

- red-cockaded woodpecker (*Picoides borealis*)
- desert tortoise (*Gopherus agassizii Cooper*)
- gopher tortoise (*Gopherus polyphemus*)
- golden-cheeked warbler (*Dendroica chrysoparia*)
- black-capped vireo (*Vireo atricapillus*)
- Indiana bat (*Myotis sodalis*)
- gray bat (*Myotis grisescens*)

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[35] Sherri W. Goodman, Deputy Under Secretary of Defense, (Environmental Security) DUSD(ES)/EQ-CO, 08 AUG 1994.

Chapter 3: Data for Identifying TES Habitat (page 35) is devoted to relating data from the life biology of these species and to how an Army manager can use the data to model habitat at the landscape scale.

DoD's Share Must Be Fair

Currently DoD is carrying a disproportionate burden of TES management.[36] The Fish and Wildlife Service tends to hold DoD installations to a higher standard than other agencies because of the perceived availability of resources within the Army/DoD. However, to successfully carry out its TES management responsibilities, DoD must cooperate with other federal, state, and local land managers in order to provide viable habitats, otherwise Army installations in particular will become unique TES sanctuaries.

Looking Beyond Installation Fencelines

In the past, military installations have been allowed to survey TES only within the boundaries of the land for which they have management responsibilities. This restriction allowed the staff to develop high-quality TES management and recovery plans for their installations while the potential TES habitats off the installation were converted to other land uses, notably agriculture or housing. This situation is recognized at high levels in DoD. Particularly, there is the sense that although Army/military lands have been well managed, other agencies and private groups have not equally shared in this national responsibility. As stated in a message from the Office of the Secretary of Defense:[37]

> 5.2.5. DOD AND THE SERVICES HAVE BEEN CARRYING A DISPROPORTIONATE COMPLIANCE BURDEN IN REGIONS SURROUNDING INSTALLATIONS, AS PROTECTED SPECIES CONTINUE TO MIGRATE TO THOSE INSTALLATIONS TO ESCAPE HUMAN ENCROACHMENT.
>
> 5.3.1. THE SERVICES AND DOD WILL WORK WITH ALL STAKEHOLDERS TO IDENTIFY AND RESOLVE ISSUES.

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[36] SECDEF MESSAGE, PUBLIC AFFAIRS GUIDANCE (PAG) FOR THE 2003 READINESS AND RANGE PRESERVATION INITIATIVE (RRPI), SECDEF WASHINGTON DC//OASD-PA/DPO//, 190100Z MAR 03.

[37] SECDEF MESSAGE, PUBLIC AFFAIRS GUIDANCE (PAG) FOR THE 2003 READINESS AND RANGE PRESERVATION INITIATIVE (RRPI), SECDEF WASHINGTON DC//OASD-PA/DPO//, 190100Z MAR 03.

5.3.2. THE SERVICES WILL WORK WITH STAKEHOLDERS IN MUTUALLY BENEFICIAL PARTNERSHIPS TO PROTECT THE ENVIRONMENT AND PRESERVE MILITARY READINESS.

5.3.3. THE SERVICES WILL STRIVE TO ENSURE ALL STAKEHOLDERS ARE AWARE OF THE POSITIVE CONSERVATION INITIATIVES HAPPENING ON MILITARY BASES IN THIS REGION.

Advantages to DoD

By delineating a region-wide spatial distribution of critical habitats for TES on and off installations, DoD and the Army can identify important locations for habitat preservation. By this objective method, beneficial partnering can be identified and acted upon so that habitat fragmentation can be limited in the most cost-effective manner.

Benefits to DoD

Benefits to the DoD to be derived from applying this approach include:

1. Application of single species research to ecosystem-wide payback.
2. Use of cost-effective, remote sensing-based technologies for determination of TES ecoregional sensitivity.
3. Lower management cost because of programmatic, ecosystem approach to land and habitat management.[38]
4. Reduction of TES management load on Army and DoD installations by objectively identifying and coordinating the responsibility for management among agencies.
5. More efficient land management, use of government resources, and cooperation within an ecoregional setting.
6. Objective, region-wide, multi-agency recommendations for land acquisition (i.e., biggest bang for the buck for the $19 million yearly land acquisition set-aside).
7. Fulfills stated requirement: "Develop larger data base for greater validity and credibility rather than focusing on small independent studies."[39]

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[38] Noss, R.F. 1991. "From endangered species to biodiversity," pages 227-246 *in* K. A. Kohm, editor. *Balancing on the Brink of Extinction: The Endangered Species Act and Lessons for the Future.* Island Press, Washington, D.C.

[39] T&E Species Advisory Group, Champaign, IL, 11 July 2001.

Examples of Common Fragmentation Tools

Although there are many specialized tools for fragmentation metric evaluations, we will take an initial look at the types of information generated by the most classical of these packages, FRAGSTATS.[40] Indices that are computed included area, patch, edge shape, core area, nearest neighbor, diversity, and contagion. Although the original FRAGSTATS was generated to deal with vector information, raster information manipulations can also be accomplished. This makes the use of satellite imagery much easier. FRAGSTATS output is usually a table of these metrics.

Fort Bragg Example

How can we relate these metrics to military lands? As an example, using the National Land Cover Data (NLCD) that covers the watershed in which Fort Bragg resides,[41] we compared the forested areas to non-forested areas. For this simple concern, Table 2-1 lists the set of fragmentation output indices included.[42]

Fort Benning Example

We do not necessarily need to use fine resolution imagery in fragmentation evaluations. (The NLCD grid used for the Fort Bragg example was 30 meters resolution.) High-resolution imagery becomes particularly cumbersome as the region of study increases in size, such as at the landscape or ecosystem level. Thus, other source imagery can be used as long as the degree of detail relates to the significant characteristics with which we are concerned. An example would be applying the data from the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) instrument over a region near Fort Benning. NASA uses the original spectral imagery from the MODIS instrument to generate products, including land cover. With it, we can use the MODIS land cover data to do a similar analysis as was done for Fort Bragg. For example, using the MODIS IBGP (International Biosphere Geosphere Programme) land cover data product at Fort Benning, we can reclassify the land uses into forested or non-forested areas (as in Figure 2-2). On this data set, we compared the forested versus non-forested regions to generate the simple set of output indices in Table 2-2.

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[40] McGarigal, L. and B. J. Marks. 1995.

[41] USGS Hydrologies Unit Code #3030004.

[42] These values were derived from PATCH Analyst 2.0, an add-on extension to ArcView3.

Table 2-1. Fragmentation output indices.

Class Name	Forested Fort Bragg (acres)	Forested Watershed Not Fort Bragg (acres)	Interpretation
Class Area	38,938.32	209,276.64	Bragg Contains over 1/5 of the forest in the watershed.
Total Landscape Area	57,399.48	209,276.64	
Number of Patches	1,880.00	3,529.00	Bragg Contains over 1/3 of the forested patches in the watershed.
Mean Patch Size	20.71	59.30	Bragg forest patches are 1/3 of the size of those elsewhere in the watershed.
Median Patch Size	0.36		
Patch Size Standard Dev	767.14	2,723.07	Bragg patch sizes vary much less than outside
Patch Size Coefficient of Var	3,703.85	4,591.87	Sizes are small, variation large, greater variation outside of Bragg (PSSD/MPS)
Total Edge	3,694,320.00	20,303,760.00	Bragg edges are 1/6 total - Bragg has less edge per clump than outside Bragg
Edge Density	64.36	97.02	Bragg edges are less dense by 1/3 than outside Bragg
Mean Patch Edge	1,965.06		
Mean Shape Index	1.15	1.37	Bragg forest patches are less complex (more regular) than those elsewhere in the watershed.
Area Weighted MSI	29.14	63.65	Bragg forest patches are only ½ as complex as those outside
Mean Patch Area Ratio	565.69		
Mean Patch Fractal Dim	1.02	1.04	Bragg Patch complexity is low, similar to those outside.
Area Weighted MPFD	1.33	1.38	Bragg Patch complexity is low, similar to those outside.

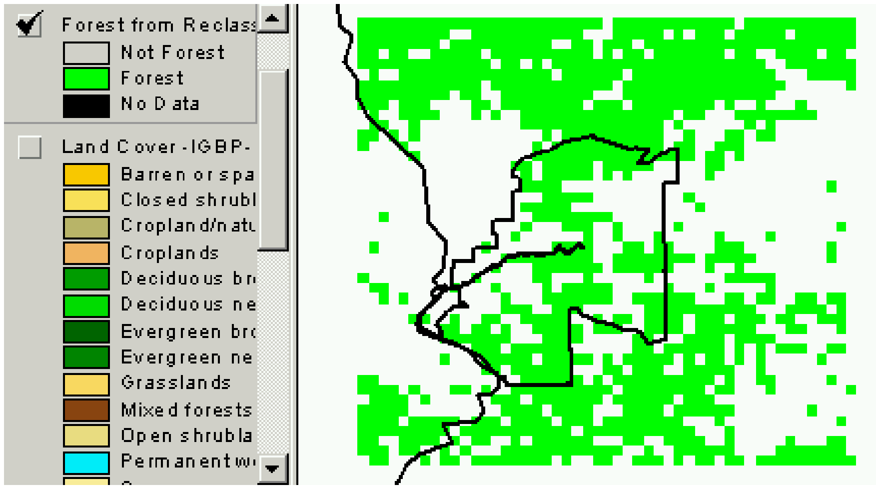

Figure 2-2. Forested/non-forested lands at Fort Benning.

Table 2-2. MODIS product landscape metric example.

Class Area	CA	198,206.57	188,520.46	Area of forested and non-forested land is about equal within the Benning Region
Landscape Area	TLA	386,727.03	386,727.03	Total Area of forested and non-forested land within the Benning Region
Number of Patches	NumP	41.00	26.00	Though the area is about equal, there are many fewer patches of forested land
Mean Patch Size	MPS	4,834.31	7,250.79	Though the area is about equal, there are many fewer patches of forested land
Patch Size Standard Deviation	PSSD	19,781.57	33,609.59	Size of forested areas varies much more than non-forested areas.
Total Edge	TE	1,585,731.30	1,623,231.70	Amount of edge is about equal
Edge Density	ED	4.10	4.20	Average amount of edge per patch is about equal
Mean Shape Complexity Index	MSI	1.37	1.41	Patches are not square in shape (not = and greater than 1)
Area Weighted Mean Shape Index	AWMSI	4.81	7.72	Forest complexity greater than non-forested areas. (Determines shape complexity independent of its size.)
Mean Patch Fractal Dimension	MPFD	1.02	1.02	The patches are simple shapes. (Mean fractal dimension approaches one for shapes with simple perimeters and approaches two when shapes are more complex.)
Area Weighted Mean Patch Fractal Dimension	AWMPFD	1.15	1.19	Forest complexity greater than non-forested areas. (Determines patch complexity independent of its size.)
Total Core Area	TCA	87,175.02	64,035.97	Foresested core area is only 3/4ths of non-forested areas.
Core Area Density	CAD	0.00	0.01	Number of disjunct core areas per hectare of total landscape is less for forested areas
Mean Core Area	MCA	4,843.06	2,371.70	The average size of disjunct core patches per hectare for forested areas is half that of non-forested areas.
Core Area Standard Deviation	CASD	13,698.36	12,023.19	Variability in core area size is about the same in both forested and non-forested areas.
Total Core Area Index	TCAI	43.98	33.97	Forest core area is greater than non-forest by about 1/3rd. (TCAI measures of the amount of core area and is low when no patches in the landscape contain core and higher as the relative proportion of core area in the landscape increases.)

Relating Biology to Fragmentation Tools

The preceeding has been intended as an introduction to the kinds of metrics and tools available. Clearly the examples do not reflect the specific needs of an individual species or an ecological region. In fact this is the challenge—to make the connection between the metrics to those characteristics that are the forcing agents in defining the character of the ecoregion at the landscape scale. It has been identified[43] that a useful first step in this process would be to constrain the reasonable range for each of these different metrics. If such ranges were defined in the literature, further refinement for the purpose of specific species or areas of concern would be greatly enhanced. Chapter 5, Population Viability Analysis (page 101) discusses how the advanced models try to make this connection and evaluates how successful they have been.

Legislation

The Development of Ecoregional Legislation

Assuming that we can identify areas of significance for particular species at the ecosystem level, the question still remains, "What do we do?" The need for some kind of legislation to support the acquisition, preservation, and conservation of lands significant to a species of concern has been identified.[44] The California Legislature passed probably the earliest example of ecosystem-level enabling legislation with the Natural Community Conservation Planning Bill.[45] This bill recognized the need

[43] Hargis, C. D., J. A. Bissonette, and J. L. David. 1997. "Understanding measures of landscape pattern," pages 231-261 *In*: *Wildlife and Landscape Ecology: Effects of Pattern and Scale*, Bissonette, J.A., ed.

[44] Noss, R.F., and L.D. Harris. 1986. Nodes, networks, and MUMs: Preserving diversity at all scales. *Environmental Management* 10:299-309.
Hunt, C.E. 1989. Creating an endangered ecosystems Act. *Endangered Species Update* 6(3-4):1-5.

[45] California Fish & Game Code §§2800-2840.

for preserving native ecosystems in their most primitive possible state. The GAP Analysis project[46] has already been mentioned as an inventory.

Army-specific Legislation

In addition to these history-making laws, the U.S. Congress has recently passed legislation enabling the Army to broaden its management options. The legislation is from the fiscal year 2003 National Defense Authorization Act (NDAA) in Sections 2811 and 2812. It allows for the implementation of Army Compatible Use Buffers (ACUB). The legislation is titled "Army Range & Training Lands Acquisition & Army Compatible Use Buffers (ACUB)."[47]

To help alleviate the pressure to meet training/testing requirements while fulfilling environmental obligations, Congress allowed the DoD to purchase property and/or property development rights from areas near installations. The law is Section 2684a of the United States Code (USC)—Agreements to limit encroachments and other constraints on military training, testing, and operations. The text of that code is presented in the Chapter 2 Attachment (page 33).

Under this law the Army has developed the ACUB program, which provides funding and management mechanisms that allow installations to develop cooperative agreements with "eligible entities" to purchase property and/or property development rights near military installations. "Eligible entities" are state governments and private organizations that are concerned with natural resource conservation. The cooperative agreements are developed to limit the opportunity for development on lands near military installations or to preserve habitats near installations in a manner that relieves installations from current environmental restrictions. Both the Army and the cooperating partners may share the costs of the property and/or property rights purchases. These purchases are being made only with willing

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[46] Scott, J.M., B. Csuti, K. Smith, J.E. Estes, and S. Caicco. 1991a. Gap analysis of species richness and vegetation cover: An integrated biodiversity conservation strategy. Pages 282-297 *in* K. A. Kohm, editor. *Balancing on the Brink of Extinction: The Endangered Species Act and Lessons for the Future.* Island Press, Washington, D.C.
Scott, J.M., B. Csuti, and S. Caicco. 1991b. Gap analysis: assessing protection needs. Pages 15-26 *in* W.E. Hudson, editor. *Landscape Linkages and Biodiversity*. Defenders of Wildlife and Island Press, Washington, D.C.
Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, J. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, J. Ulliman, and R.G. Wright. 1993. Gap analysis: A geographical approach to protection of biological diversity. *Wildlife Monographs* 123:1-41.

[47] Ted Richan, INFORMATION BRIEF FOR FY03 RANGE SYMPOSIUM, Army Range Programs DAMO-TRS, 703-692-6445.

private land owners and the agreement process involves substantial cooperation with all affected stakeholders. The ACUB program does not facilitate the acquisition of new training land, but rather the acquisition of important habitat land near installations that, in turn, allows and sustains training and testing on existing installation land.

The ACUB proposal process is shown in Figure 2-3; it involves coordination among the Army Assistant Chief of Staff for Installation Management (ACSIM), the installation, a suitable Non-Government Organization (NGO) under the terms of section 2684a, and local stakeholders and interested parties.

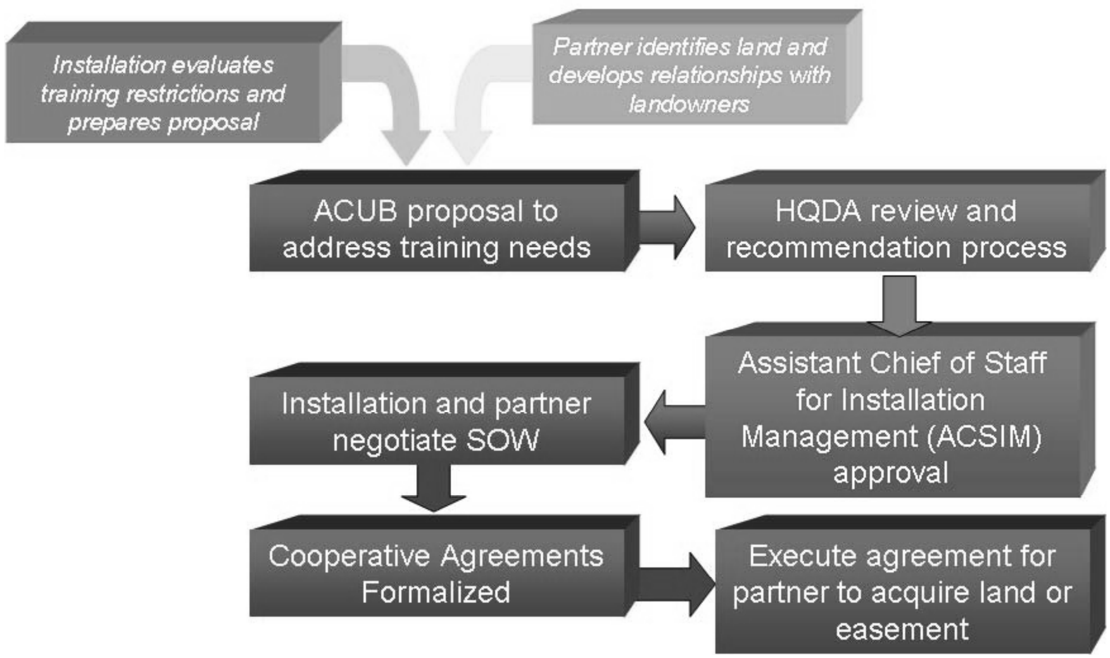

Figure 2-3. The ACUB proposal process.

Range and Training Land Acquisitions are defined as acquisitions by purchase, lease, transfer, donation, permit, withdrawal, or exchange of real property or an interest therein for range or training purposes. Army Headquarters has overall management responsibility for the range and training land acquisition program. ACUBs are defined as formal agreements between the Army and eligible entities for acquisition by those entities of land or an interest in land (including water rights) from willing sellers. The intent of these formal agreements is to limit encroachment through the methods of acquisition of development rights, cooperative agreements, conservation easements etc. ACSIM has overall management responsibility for the ACUB Analysis of Alternatives Study (AAS).

Through this Army Headquarters initiative, installations are encouraged to examine land ownership and land use adjacent to major installations to identify opportunities for ACUBs and to support a strategy for Army-wide application of the Fort Bragg experience.

Military Departments and private conservation groups have mutual interests in preserving open space:

- As buffers against urban sprawl
- To enhance training and testing ranges
- To preserve habitat, watersheds and open space
- To enlarge habitat area to reduce pressures on Army missions.

Certain conservation groups have high levels of experience in real estate transactions and can assist in rapid land acquisitions. They tend to have excellent public/regulator relations and are able to leverage limited dollars to provide a high return of stewardship costs over the long term.

The legislation supporting the Army Compatible Use Buffers came in fiscal year 2003 as part of the National Defense Authorization Act—NDAA. Section 2811 of the NDAA says that DoD may cost share the purchase in fee or easement with Non-Public Organizations (NPOs) for the purposes of limiting encroachment, or supporting training and conservation. Items covered include water rights, Operations and Maintenance (O&M), and Research Development, Testing and Evaluation (RDT&E) funds. DoD is allowed to accept NPO appraisals with willing sellers. In another part, Section 2812, the lands may be conveyed to states, political subdivisions, or NPOs as long as conservation is a required use.

Army Headquarters has sent out a Memorandum[48] that establishes the content and format of ACUB proposals. Proposals are to include a description of the purpose and need for the action, a description of the proposed action and a preliminary list of alternatives to that proposed action (including the "no action" alternative), and an explanation of funding estimates and how they will be budgeted or programmed. A brief description of potential issues of concern or controversy, a timeline with milestones, a public Participation Plan, and map(s) of the proposed action must be included. Those eligible to participate with DoD on an ACUB action include many established conservation groups such as The Nature Conservancy (which takes an eco-regional approach to defining critical habitats), the Trust for Public Lands, the Land Trust Alliance, the Conservation Fund, the Trust for Land Restoration, and The

[48] DOT/ACSIM Memorandum, Army Guidance, 19 May 03.

Gift Fund. There are already over 1500 land trusts across the country. Many of these groups have expressed interest in partnering with Army.

The Army has a two-phase ACUB land strategy. In Phase 1, administrators will provide a framework and methodology to identify priorities for Army Training Land Acquisitions and ACUBs. Phase 1 is intended to identify training installations where the mission can be enhanced in the long term. In Phase 2, officials will provide a methodology to identify priorities for joint land use at existing DoD installations and for major acquisitions of new Lands for Joint Military Training Actions (MTAs). The strategy does not preclude any installation from seeking an acquisition or ACUB.

Summary

Military installation managers are required by state and federal regulations to protect certain threatened and endangered species. One of the primary threats to these species is habitat loss that not only decreases the landscape carrying capacity for these species, but also fragments the landscape, decreasing the genetic flow among populations and the potential for natural repopulation following local extirpating disasters. The issue of endangered species is becoming increasing important, and the issues with individual species are just a reflection of the general status of the ecosystems. The earth is experiencing loss of habitat, in general due to increased industrialization and urbanization, resulting in dramatically decreasing biodiversity. Although the news media may decry the loss of large sections of ecosystems in exotic areas (such as the tropical rain forests in South America), the installation land manager can make a positive impact on this situation at home. The decrease in biodiversity and the loss of functioning natural ecosystems within the United States has been as great as or greater than in areas outside the United States. The Endangered Species Act is the response of our national political system to the much larger issue—the issue of ecosystem loss as a result of the fragmentation of our natural landscapes. Each landscape and the species that comprise the community vary greatly. In the eye of the public, fragmentation may be patches of forest, but fragmentation is different for each individual species. In fact, fragmentation for a deep-woods bird is the opposite of fragmentation for a forest edge species. Fragmentation discussions, therefore, always have to be in reference to a particular species. Agencies such as the Department of Army may have the legal responsibility to react to the ESA, but dealing with one species at a time has been shown to be ineffective and very costly.

Although a comprehensive ecosystem management program could easily be more expensive than a management plan for a single species, it becomes obvious that the cost/benefit quickly switches to favor a plan that includes multiple species. Almost every installation has more than one species of concern, either currently listed or a possible emerging candidate. So even now, the benefit is positive. A plan that attempts to capture the benefits to 85 percent of the species and most of the important physical processes of a region:

- Benefits the region as a whole along with its component species,
- Preserves those processes that originally made the region economically viable,
- Attempts to balance the demands of the natural physical systems with the demands of future development,
- Avoids the future listing of new species, thus saving on future additional single species management plans,
- Contributes to the sustainability of the local communities as well as the installations, and
- Encourages cooperation with agencies and non-governmental organizations for the overall benefit of a region.

Suppose for a moment that a single species approach remains the military's approach. In contrast one can expect:

- As habitat fragmentation continues, additional species will become endangered, each new species requiring another in an endless (and sometimes contradictory) line of management plans.
- As habitat fragmentation continues outside the installation boundaries, the newly listed species remaining on the installation will increase the already disproportionate responsibility on the military and likely further limit its ability to carry out its primary training and testing mission.
- Regional natural physical systems will continue to degrade further, making the sustainability of the installation as well as the local communities ever less viable.

Which scenario would a prudent individual or government chose to pursue? The point for the land manager is that dealing with fragmentation at a landscape scale will result in multiple benefits while dealing with TES individually has been shown be result in questionable and occasionally conflicting returns.

The theoretical bases for dealing with issues of habitat fragmentation and the technological capabilities to carry out the theory have been developing quickly. The conceptual framework has been variously called landscape ecology, ecosystem health, or community-level conservation. The basic thrust is that to effectively deal with individual species you must deal with the community in which they reside. The unit can be defined as an ecosystem at a landscape scale. Landscape-scale ecology has been developing over the past many decades, beginning with the innovative work of people like Aldo Leopold. Issues dealing with landscape-scale health were too complicated to address when the only technology available was to physically lay different maps on top of each other to find land patterns. In the past three decades, however, the emergence of GIS as a technological tool and remote sensing (largely satellite imagery) as a basic data source has begun to fill the technology gap. So only recently has the ability to deal with questions of TES habitat fragmentation emerged at the scale where it is appropriate—the regional or landscape scale.

Ecology can be studied at a variety of levels, from the microscopic to the whole earth. Over time, and as technology advanced, it has become more practicable to deal with larger and larger scales or frames of reference. The initiative by the National Park Service, Environmental Protection Agency (EPA), and USGS called the GAP Analysis was the first and best-known attempt to tackle issues of shrinking healthy natural communities at regional, national, and global scales. In fact the name GAP is not an acronym; it really refers to the gaps between existing islands of fully functioning ecosystems.

Along with other federal agencies, the military, and specifically the Department of the Army, must respond to legal requirements to manage the lands under its jurisdiction for both their primary missions and for the preservation of threatened and endangered species that reside within their legal boundaries. Since very few of the TES that exist on military installations reside only within an installation, effective management must be coordinated beyond those installation boundaries; that is, at a landscape scale. As has been shown, management for a single species, even a species for which management is legally required, is most effective through management of the entire healthy ecosystem.

Hundreds of "Species of Concern" (SOC)[49] inhabit military lands. The Army has adopted a small group of species as most critical to manage correctly so that these TES do not interfere with the Army's main objective: military readiness training and weapons testing. Some of the most comprehensive and effective TES manage-

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[49] In the report *Species at Risk on Department of Defense Installations, Revised Report and Documentation* (prepared for the DoD and U.S. Fish and Wildlife Service, January 2004), SOC are defined as native, regularly occurring species in the United States that are either:

- Candidates under the U.S. Endangered Species Act, or
- Considered by NatureServe and the Network of Natural Heritage Programs to be critically imperiled (rounded global rank of G1 or T1) or imperiled (rounded global rank of G2 or T2) and have not been federally listed.

In this report, SOC include federally listed species.

ment programs have been carried out on Army lands. A problem has emerged which makes the preservation and management of TES more difficult: increased urbanization. Whereas, in the past Army lands were away from population centers, these lands remained in their most natural form as surrounding areas became industrialized and urbanized. In the past few decades there has been a shift in the perception of many Americas that these remaining natural lands have become more attractive because they have retained their natural appeal. The isolation that military installations had previously enjoyed has given way to being in those areas that are now also attractive for development. As development increases outside of the military installation boundaries, the habitat of many species disappears and the habitat that remains has become more fragmented for those species. Thus, the military installations have become refuges of natural habitat in what is becoming a sea of development. The remaining natural areas can be characterized as fingers largely running along the rougher topography and riparian areas. The military has accommodated the requirements of the U.S. Fish and Wildlife Service in their enforcement of ESA regulations, but the management of TES species is not the primary mission of the Department of Defense; the mission of the DoD is readiness training and materials testing. The DoD has and will continue to be environmentally friendly, but the regional scale of fragmentation stipulates that the Department of Army cannot be the only responsible agency or landowner responding to these requirements. Success for TES husbandry requires cooperation at high levels of ownership and management.

Fortunately, recent events have empowered the Department of Army with the ability to respond to some of the challenge that is stirring beyond the installation boundaries. Several new initiatives by Congress have allowed installation managers to begin to deal with agencies and interest groups responsible for lands near but outside the installation boundaries. The most notable of these is the ACUB initiative. The supporting legislation allows installations to develop cooperative agreements with environmental groups managing nearby lands for the purpose of long-term conservation. Since the most pressing issue the military has in terms of managing its land is the management of the TES species on its lands, the ACUB legislation has the potential of allowing some of the installation's TES responsibility to be accommodated, in part, via these nearby lands, thus reducing the potential of a conflict between the preservation of TES and the military training and testing mission.

The ability to deal with the complicated issues of habitat fragmentation is beginning to emerge. The theoretical basis for dealing with questions of a regional ecological character is developing hand-in-hand with technologies that will be able to sustain the scientific application of good land management theories. Further, both national and state legislatures are now beginning to provide enabling legislation so questions of land management can be dealt with at a scale greater than any single stakeholder or agency can deal with on its own.

Chapter 2 Attachment: Section 2684a USC, Agreements to limit encroachments and other constraints on military training, testing, and operations

(a) Agreements Authorized. The Secretary of Defense or the Secretary of a military department may enter into an agreement with an eligible entity described in subsection (b) to address the use or development of real property in the vicinity of a military installation for purposes of:

(1) limiting any development or use of the property that would be incompatible with the mission of the installation; or

(2) preserving habitat on the property in a manner that

(A) is compatible with environmental requirements; and

(B) may eliminate or relieve current or anticipated environmental restrictions that would or might otherwise restrict, impede, or otherwise interfere, whether directly or indirectly, with current or anticipated military training, testing, or operations on the installation.

(b) Eligible Entities. An agreement under this section may be entered into with any of the following:

(1) A State or political subdivision of a State.

(2) A private entity that has as its stated principal organizational purpose or goal the conservation, restoration, or preservation of land and natural resources, or a similar purpose or goal, as determined by the Secretary concerned.

(c) Inapplicability of Certain Contract Requirements. Chapter 63 of title 31 shall not apply to any agreement entered into under this section.

(d) Acquisition and Acceptance of Property and Interests.

(1) An agreement with an eligible entity under this section may provide for:

(A) the acquisition by the entity of all right, title, and interest in and to any real property, or any lesser interest in the property, as may be appropriate for purposes of this section; and

(B) the sharing of the acquisition costs by the United States and the entity.

(2) Property or interests may not be acquired pursuant to the agreement unless the owner of the property or interests consents to the acquisition.

(3) The agreement shall require the entity to transfer to the United States, upon the request of the Secretary concerned, all or a portion of the property or interest acquired under the agreement or a lesser interest therein. The Secretary shall limit such transfer request to the minimum property or interests necessary to ensure that the property concerned is developed and used in a manner appropriate for purposes of this section.

(4) The Secretary concerned may accept on behalf of the United States any property or interest to be transferred to the United States under the agreement.
(5) For purposes of the acceptance of property or interests under the agreement, the Secretary concerned may accept an appraisal or title documents prepared or adopted by a non-Federal entity as satisfying the applicable requirements of section 301 of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (42 U.S.C. 4651) or section 3111 of title 40, if the Secretary concerned finds that the appraisal or title documents substantially comply with the requirements.

(e) Acquisition of Water Rights. The authority of the Secretary concerned to enter into an agreement under this section for the acquisition of real property (or an interest therein) includes the authority to support the purchase of water rights from any available source when necessary to support or protect the mission of a military installation.

(f) Additional Terms and Conditions. The Secretary concerned may require such additional terms and conditions in an agreement under this section as the Secretary considers appropriate to protect the interests of the United States.

(g) Funding.
(1) Except as provided in paragraph (2), funds authorized to be appropriated for operation and maintenance of the Army, Navy, Marine Corps, Air Force, or Defense-wide activities may be used to enter into agreements under this section.
(2) In the case of a military installation operated primarily with funds authorized to be appropriated for research, development, test, and evaluation, funds authorized to be appropriated for the Army, Navy, Marine Corps, Air Force, or Defense-wide activities for research, development, test, and evaluation may be used to enter into agreements under this section with respect to the installation.

(h) **Definitions** (in this section):
(1) The term "Secretary concerned" means the Secretary of Defense or the Secretary of a military department.
(2) The term "State" includes the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Marianas, and the territories and possessions of the United States.

3 Data for Identifying TES Habitat

Dr. Charles Ehlschlaeger, Robert Lozar, Dr. Harold Balbach and Dr. James Westervelt

Overview

This chapter was written for the managers and developers of GIS databases for the purpose of TES habitat and life-requirements delineation. This chapter identifies spatial data that the life-histories of the TES require and provides a list of corresponding data products useful to the ACUB program for the purpose of identifying TES habitat needs. These data products will also provide a foundation of knowledge for the long-term monitoring for TES habitat change. The ACUB program allows Federal funds to be used to enter into partnership agreements with county, state, and municipal governments, as well as nonprofit organizations to purchase property and property rights that will reduce the habitat fragmentation threat and ensure the sustainability of the military training mission well into the future. Habitat fragmentation is considered a leading challenge to the maintenance of TES populations. Human development upon the natural landscape is a major cause of TES habitat fragmentation. Although pollution, invasive species, and other factors have contributed, it is mostly the impact of years of habitat fragmenting that threatens a species' ability to survive. Military installation training activities are no exception in their contribution to fragmenting TES habitats. But if incompatibilities are not resolved, the TES may then put into question the continued sustainability of the installation-training mission.

The Military Perspective

Training on Military Lands

Unlike almost any other agency in the United States, the military in general and the Army in particular have an unusual requirement on their use of their lands. To carry out its training mission, the Army must intensely use its lands for heavy tracked and wheeled vehicle maneuvers while at the same time preserving those lands in a natural appearing state. Although these seem to be conflicting requirements (and occasionally they are), training, testing, and other operations can be conducted and carried out in such a manner as to not negatively affect natural habitats and specifically to not jeopardize threatened and endangered species. In order to manage its lands appropriately and to take advantage of the possibilities of new technologies and social thrusts, the military needs to understand clearly the characteristics of the species and to identify those items that will be most useful in managing their niche in the ecosystem.

Exit Criteria

The Government Accounting Office (GAO) has been involved[50] in developing criteria intended to help the Army (military) identify explicitly when it has accomplished as much management action as is reasonably possible in managing and safeguarding TES habitats within their control. Some progress has been made toward identifying these criteria.[51]

From these criteria, basic and applied research exit criteria have been developed[52] as a part of the research and technology program during the current decade. As an addition to these Environmental Exit Criteria, the Army Environmental Quality Technology Program includes considerations of larger ecosystems, habitat fragmentation, and encroachment as part of this issue.

Why TES Habitat Must Be Identified

The Army Environmental Research Requirement 4.6a: *Reducing Impacts of Threatened and Endangered Species on Militaty Readiness* explains why we need to know about each species in detail:

> There is an urgent need to know the impact of military-unique actions on Threatened and Endangered (T&E) species and Species of Concern (SOC), their habitats, and associated ecosystems to effectively carry out military readiness missions and comply with the legal requirements to conserve the

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[50] Exit Conference for GAO review code 350268 "Regional Management of the Endangered Species Act by DoD and Other Federal Agencies" July 2003, Arlington, VA.

[51] U.S. General Accounting Office, *Military Training: DOD Lacks a Comprehensive Plan to Manage Encroachment on Training Ranges,* GAO-02-614 (Washington, DC, June 11, 2002); U.S. General Accounting Office, *Military Training: DOD Approach to Managing Encroachment on Training Ranges Still Evolving,* GAO-03-621T (Washington, DC, April 2, 2003).

[52] From Army Environmental Requirement A (4.6a), Title: Reducing Impacts of Threatened and Endangered Species on Military Readiness.

> species. The knowledge of the effects of military activities will allow conservation efforts to be directed toward mitigation of real, not speculative, training impacts. Without this knowledge, the Endangered Species Act regulators are forced to hold the Army to the most stringent standards to protect T&E species on Army lands, thus regulatory restrictions are more severe. It is likely that many training restrictions have been imposed due to a lack of knowledge of the effects of military activities on individuals or populations. The focus of this requirement will be on the military impacts of noise, smokes and obscurants, maneuver (including excavation), and environmental contaminants.[53]

Requirement 4.6a also explains the need to deal with Habitat Fragmentation (the subject of this report):

> There is a need to avoid/manage habitat fragmentation. Habitat fragmentation is recognized to be the single greatest threat to biodiversity globally. Fragmentation includes both loss of habitat and isolation of increasingly smaller parcels of essential habitats. Maneuver training needs to avoid fragmentation effects on T&E species and SOC habitats.[54]

Army TES

Although the Department of the Army is responsible for maintaining the habitats of many species of various levels of concern, it has identified a specific set that are of the highest priority. The rest of this chapter is devoted to characterizing the life biology of these species and relating that information to how an Army manager can use it to model habitat at the landscape scale.

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[53] The Army Environmental Research Requirement 4.6a: *Reducing Impacts of Threatened and Endangered Species on Military Readiness*.

[54] The Army Environmental Research Requirement 4.6a: *Reducing Impacts of Threatened and Endangered Species on Military Readiness*.

Discussion of the Qualities of Data Needed To Accomplish Landscape-Scale Fragmentation Monitoring and Analysis

Relation to Spatial Modeling

To make the connection between the needed data and the available data, it is necessary to define a generalized process into which the needed and available data can be entered; basically TES habitat modeling in a GIS environment. This section is not intended to be a complete description of the habitat suitability models for important TES but rather its purpose is to provide a framework for dealing with the issues of basic input data. A review of many of the standard TES viability models is presented in Chapter 5, Population Viability Analysis, page 101).

Step One: Identify data layers that define critical habitat concerns (e.g., nesting and feeding locations or soil types) for a particular TES.

Step Two: For each data layer, generate a map with values between 0 and 1.

In the map, a location with a value of 0 would indicate that the location would prevent a positive benefit for the species for that data layer (e.g., water would prevent nesting for many birds), while a value of 1 would indicate a perfect condition of that data layer for the TES under study. A value between 0 and 1 would indicate a corresponding degree of acceptableness of that data layers' item for the TES under consideration.

Step Three: Determine the weighting of each data layer for each TES. The weighting factors can be determined qualitatively by analyzing habitat description if limited survey data is available. Ideally, the weighting factors should be determined by regression analysis with extensive survey data.

Step Four: Perform a favorability function analysis to determine, for example, *potential TES habitat* on a cell-by-cell basis. Favorability functions are discussed extensively in *Geographic Information Systems for Geosciences*, 1995, by G. Bonham-Carter, and compared against other favorability functions in *Geographic Information Analysis*, 2003, by D. O'Sullivan and D. Unwin. It is best to normalize the equation of a favorability function analysis with:

$$F = \frac{\prod_m w_m X_m}{\prod_m w_m} \quad \text{Equation 1}$$

where:

F = the favorability function map

w_m = weight of data layer m

X_m = data layer m.

Step Five: The *potential TES habitat* map is then used as an input to a neighborhood analysis to create a *quality TES habitat* map. The neighborhood analysis will ensure that enough potential habitat exists around specific potential habitat grid cells to provide for genetic diversity at that location. These steps are done for each species, so it is already interated into the procedure as described. This process can be complicated by accounting for barriers (roads and urbanized areas) or specific TES issues such as the gray bat's need for protective flight paths between their caves and feeding areas.

Data Products Factors for TES Habitat Identification and/or Monitoring

Several factors must be considered before choosing data products that will identify and/or monitor TES habitat:

- An ideal data product will either be useful in modeling TES habitat over time, or it will provide a highly accurate and precise measure of current or potential TES habitat, or both. In other words, data products that are precise and accurate are also poorly suited to monitor TES habitat and vise versa. Precise and accurate data usually take years to produce, take up much disk space, and often are available at infrequent intervals. Monitoring data, which must be available at frequent intervals, should be coarse and inexpensive. For example, Table 3-1 contains estimated costs of various satellite products. The highest resolution satellites, such as Ikonos and SPOT, would be extremely expensive relative to lower resolution data products. While not intuitive, the "Relative Disk Size" column is the best representation of the true cost of processing remotely sensed data. Disk Size refers to the relative size various data products would occupy on a hard drive. The size of the file indicates how much time it would take for remote sensing software, and the remote sensing expert, to classify or modify the original raw images.

Table 3-1. Estimated costs of various satellite products

Satellite	Resolution	Time Series	Relative Disk Size	$/acre/year
Ikonos	4 meter	3 day	17787	$7.42
Quick Bird	3 meter	7 day	13552	$4.23
SPOT	10 meter	26 day	329	$0.053
Indian Remote Sensing	24 meter	5 day	297	$0.038
Landsat	30 meter	16 day	66	$0.0032
MODIS	231 meter	16 day	1	Free

- Data layers should be flexible, allowing multiple uses. For example, the National Land Cover Dataset, or NLCD, can be reclassified or analyzed into nine separate and useful data layers for identifying TES habitat.

With these data products factors we are attempting to achieve two goals in defining the data themes appropriate for ACUB program: (1) identifying and (2) monitoring TES habitat. Chapter 6, Data Quality for Themes Monitoring Threatened and Endangered Species Habitat, page 127 discusses the adequacy of the data themes discussed in this chapter for long-term monitoring of TES.

Many of these data products come from government agencies, but can also be purchased from private vendors. Private vendors will often make the data easier to import into GIS software. For example, various population demographic variables are useful in predicting population growth that affects TES habitat loss. GeoLytics and Claritas provide software that generates ESRI shapefiles of census blocks containing desired demographic variables.

Potential Existing Data Products

Following is an initial candidate list of potential habitat suitability layers, organized by the data products and from where the data products are available.

National

Soil Survey Geographic DB (SSURGO)

- High surface runoff
- Deep, well-drained, sandy substrate at least 1m above seasonal water table

National Land Cover Data (NLDC)

- Mixed deciduous and coniferous tree cover
- Coniferous tree cover
- Shrub cover
- "Nectar corridor" with shrub cover in Southwestern U.S.
- Deciduous forest
- Forest cover
- Water bodies
- "Fragmented places" with grassland cover adjacent to shrubs or forest

U.S. Census Data

- Population counts for census blocks to determine population density

National Elevation Data: at 1, 1/3, (and 1/9 where available) arc-second resolution

- Steep Canyon Slopes
- Rough Terrain
- Elevations 900-1,500m
- Sunny areas
- Flat or rolling hills

EPA: Storage and Retrieval system (STORET)

- Water quality information for lakes and rivers

State and Local

Traffic load on existing highways

Parcel zoning maps

Non-Governmental Organizations:

The Nature Conservancy, Ducks Unlimited, etc.

Field surveys of TES nests, forage locations, and trails.

In summary, the potentially useful TES habitat identification data products that are available now include:

1. 30m resolution National Land Cover Data (NLCD) to model:
    - Large tracts of mixed deciduous and coniferous tree cover,
    - Coniferous tree cover,
    - Deciduous tree cover,
    - Protective canopy flight corridors,
    - Large bodies of water,
    - Shrub cover and nectar corridors,
    - "Fragmented places".

3. Use U.S. Census block level data to determine population density for various locations and land cover types.

4. National Elevation Data to model:
- Steep canyon slopes,
- Rough terrain,
- Elevations 900-1,500m,
- Flat and rolling hills.

5. Soil Survey Geographic DB (SSURGO) for:
- High surface runoff,
- Deep, well-drained, sandy substrate at least 1m above the seasonal water table.

6. The U.S. Census Bureau Typologically Integrated Geographic Encoding and Referencing System (TIGER) files to locate large bodies of water.

8. EPA STORET water quality information: http://www.epa.gov/storet/.

Species Profiles for Each High-Priority Army TES

Procedure

For each of the following species, notes are presented regarding how life characteristics can be used in formulating Landscape Scale Fragmentation Monitoring and Analysis specific for that species. To accomplish this, a very short description per species is given. From this descriptive material and from a companion document[55] that more fully describes these species, statements are generated for each species in a concise standard format and include a description of potential landscape scale TES species-specific concerns that are needed and have the potential of being available in a spatial data format. At this point, we are only identifying needs.

[55] Balbach, H.E., *Profiles for High-Priority Species.* ERDC/CERL Technical Report DRAFT, TRxxxxx, September 2006.

Species profile – Red-cockaded Woodpecker (Picoides borealis)

Brief Life History: The red-cockaded woodpecker's (RCW's) range is closely tied to the distribution of southern pines. RCW nest in open stands of pines with a minimum age of 80. Historically, longleaf pines (*Pinus palustris*) were most commonly used, but numerous other species of southern pine are also acceptable. Nest cavities and successful colonies have been found in loblolly (*P. taeda*), shortleaf (*P. echinata*), slash (*P. elliottii*), and Virginia (*P. virginiana*) pines. Foraging habitat is provided in pine and pine hardwood stands 30 years old or older, with a foraging preference for pine trees 10 inches or larger in diameter. RCW foraging (a subset of the minimum habitat) can be provided in 80 to 125 acres of pine forest. The main criterion appears to be that the cavity trees must be of adequate size (at least 12 inches in diameter, and preferably larger). Forest canopy cannot be continuous. The territory for a RCW group averages about 200 acres, but observers have reported territories running from a low of around 60 acres to an upper extreme of more than 600 acres. The RCW is a listed species solely due to loss of habitat. Private timber stands in the southeastern United States are generally on short rotations (less than 45 years) that do not permit trees to attain the characteristics sought by RCW. Only 2.5 percent of the current pine acreage in the Southeast is considered suitable RCW nesting habitat. To reduce mid-story encroachment, fires should occur every 2 to 3 years.

Habitat: The RCW requires pine forests, containing older trees (minimum of 80 years); longleaf pine is the most desirable. An open crown is required. The preferred land cover is savanna with overstory of scattered Pines. The RCW's home range is roughly a 300- to 750-m radius.

Habitat Maintenance: Frequent (every 3 to 5 years) "cool" fires are important to allow older pines to live but to keep down midstory hardwoods. Frequency and intensity of fires can be determined from NASA EOS satellites, particularly the MODIS and MISR instruments. These instruments can see understory fires because they sense the heat signatures. The RCW will not colonize areas with commercial forestry and will avoid hardwoods encouraged by commercial forestry.

Foraging: Longleaf pine landcover type is best for foraging. Evergreen landcover is good; even hardwood is OK, but not near nesting locations.

Nesting: The RCW requires areas of open crown in older pine trees, preferably longleaf pine. The preferred land cover is savanna with an overstory of scattered pines. RCW use the sap of nearly dead longleaf pine trees to make it more difficult for its eggs to be eaten by the indigo snake, another species of high Army concern. RCW are social birds that nest in colonies a minimum of 60 acres in area.

Migration: RCW do not disperse very far; 4 km is the range a bird can be expected to travel to establish a new nest/colony. Dispersal decreases greatly beyond that distance, although occasional flights of 120+ km are known. The presence of highways may increase this distance.

Required Acres: Patches of 200 acres minimum are necessary. Larger patches increase viability, and are therefore more desirable. Patches with metrics showing greater “edge” are less desirable.

Data Currently Available To Support Modeling RCW Over Large Regions:
1. Use 30 m resolution *National Land Cover Data* to model coniferous forest.
2. U.S. Census block population counts for population density.

*Species Profile – Gopher Tortoise (*Gopherus polyphemus*)*

Brief Life History: Gopher tortoise (GT) habitat is characterized by upland areas with deep, well-drained, sandy substrate suitable for construction of extensive GT burrows. The habitat must be at least 1 m above the seasonal water table. GT prefer relatively open-canopied habitats, generally less than 50 percent cover, with sunlit areas for nesting and thermoregulation. GT habitat is most commonly associated with open pine woodlands, with a reliable, low-level herbaceous groundcover for a food supply. GT may be found in many types of sparse broadleaf woodland, particularly scrub oaks of various species. This description is common of sandhill ecosystems originating from marine sand deposits in the Plio-Pleistocene geological period from 5 to 15 million years ago. The GT habitat's primary plant community is composed of longleaf pine, turkey oaks, and wiregrass. These plants are fire resistant, and in fact, the entire community is called a fire subclimax forest. Other prominent plants include lichens, yuccas, palmetto, shrubs, wildflowers, gopher apple, and prickly pear cactus. GT habitat requires burning on a regular cycle. GT numbers may be reduced by as much as 60 to 80 percent when burning is excluded for 8 or more years. Urban displacement, phosphate mining, and citrus production is prime causes of GT habitat loss. Popular forest management practices, which emphasize dense plantings of loblolly pine, destroy food plants, inhibit nesting, and cause tortoises to relocate to the edge of roadsides and ditch banks.

Habitat: GT prefer a fire subclimax open forest of pine, turkey oaks, and wiregrass on arid sandy coastal upland. They need open (greater than 50 percent cleared) canopied areas for sunning (thermoregulation). Habitat is always in a dry, well drained, sandy substrate (required for burrowing), with seasonal high water table greater than 1m deep in sand hills or some disturbed communities. The GT's historic distribution coincides with longleaf pine on sandy uplands and coastal plain soils. An open crown/canopy is required. Preferred land cover is savanna with an overstory of scattered pines. During daily activity, an individual GT ranges from 0.8ha to 1.27 ha around its burrows. Viable populations require about 50 burrows within an area of 20 to 40 ha (50 to 100 acres). A dense, deciduous midstory is undesirable. Gopher tortoise may reside near roads if better habitat is removed, but they are then likely to become roadkill.

Habitat Maintenance: Frequent (every 3 to 5 years) "cool" fires are important to preserve groundlevel herbaceous food source. Unburned broadleaf underbrush is undesirable. The frequency and intensity of fires can be determined from NASA EOS satellites, particularly the MODIS and MISR instruments.

Foraging: The regular supply of food for the GT consists primarily of grasses, succulent herbaceous plants, and legumes. Legumes appear to be particularly important in the diet of juveniles. An adequate 3- season food supply is required. Relatively litter-free ground is necessary for food production.

Nesting: The GT requires sandy soils to dig a hole to place the clutch, usually near the burrow. An open crown is required for sunny exposure to warm and hatch the eggs. It is a social species that develops burrow in groups in a minimum 30-acre area. Relatively litter-free ground is necessary for nesting.

Migration: Although a tortoise will travel up to 1 kilometer per day, dispersal in the range of 10 kilometers is possible if the route is not cut off by highways. Road-kill is common.

Required Acres: Although a gopher tortoise's life is spent near its burrows, ranges of 10 hectares (25 acres) are not uncommon for males. Patches of about 50 acres minimum are necessary. These animals are social; a population of about 50 breeding-age animals is required for a healthy grouping. Highways, gas pipelines, and urban and agricultural uses fragment habitat. Patches with metrics showing greater "edge" are less desirable. Higher fragmentation metrics indicate a poorer environment.

Comment: Although the RCW and GT have slightly different requirements, it is not a coincidence that their historic range was often the same as the longleaf pine. Because of the restriction of the longleaf pine's distribution, the RCW and GT have become TES. Thus, this pair makes an excellent example of the effectiveness of managing healthy ecosystems rather than focusing on single species. Not only will the two TES recover, but also the people of the country will benefit from the other contributions a healthy ecosystem provides.

Data Currently Available to Support Modeling GT Over Large Regions:
1. Use 30 m resolution *National Land Cover Data (NLCD)* to model coniferous tree cover.
2. *Soil Survey Geographic DB (SSURGO)* for deep, well-drained, sandy substrate at least 1m above the seasonal water table.
3. National Elevation Data: at 1, 1/3, (and 1/9 where available) arc-second resolution to determine sunny areas.
4. U.S. Census block population counts for population density.

***Species Profile for Golden-cheeked Warbler* (Dendroica chrysoparia)**

Brief Life History: The golden-cheeked warbler (GCW) requires ash juniper trees more than 20 years old mixed with deciduous trees, particularly oaks, in dense, large (1.2 to 8 ha minimum) stands. Ash juniper has a bark that can be stripped easily and is used as nesting material. Prime GCW habitat seems to be steep canyon slopes with rugged terrain and limestone geology. This prime habitat may exist because of greater surface runoff. Mature forested areas with 50 percent or greater canopy cover in flat or rolling uplands are also likely to attract breeding warblers. Additionally, GCW may use patchy woodlands containing mature oaks and junipers. Although patchy woodlands may not attract breeding individuals, or may not represent ideal breeding habitat, these areas may support fledglings after the peak breeding period. Patchy or flat woodlands surrounding ideal breeding habitat can function as a buffer and may serve to protect GCW populations from other land-use practices, including cattle grazing, urban growth, and agricultural practices. A woodland buffer of at least 300 feet around patches of high-quality breeding habitat is recommended. Ironically, burning of GCW habitat results in good habitat for the black-capped vireo (*Vireo atricapillus*). *V. atricapillus* is also a TES discussed later.

Habitat: Preferred GCW habitat is within the Edwards Plateau, Lampasas Cut Plains, and Llano Uplift in the later successional stage of mixed juniper-dominated shrubs and grassland. This habitat is restricted to moderate-to-high density mature stands of ash juniper (minimum of 15 feet tall, and at least 25 years old) mixed with other deciduous tree species, particularly oaks. The birds need rough (high slope) canyon topography and moist soils near a required water source (creek, draw, spring, seep). The mature ash juniper stand can include oaks, ashs, elms, or walnuts. A juniper/deciduous mix of varying height, rather than a pure stand of juniper, is most desirable. Dryer, flatter uplands of more than 50 percent canopy cover of post, live, and blackjack oak provide a poorer, less dense habitat. Unfortunately, the upland habitat is susceptible to being converted to incompatible agriculture, residential, commercial timber, or pasturelands. Canyon lands are susceptible to being impounded for lakes, an action that also destroys prime GCW habitat. Larger, unfragmented tracts of land are more desirable because fragmentation invites greater predatory losses. Urban fragmentation greatly increases cat predation. Increased fragmentation makes recolonization of available habitat more difficult.

Habitat Maintenance: The current habitat is a result of the steep, rough areas not being converted to pasture, agriculture, or urban development. In addition to the steep remnant areas that currently exist, nearby uplands can provide habitat for GCW at lower densities. Fire or selective young growth removal must occasionally occur to provide the varied height and tree type requirements. During the nonbreeding season, removal of juniper trees less than 10 ft (3 m) tall is permitted. Loss of oaks to oak wilt disease can be monitored with remote sensing, which can pick out unhealthy vegetation compared to healthy vegetation of the same species.

Parasitic Threats: With both the GCW and black-capped vireo (BCV, discussed later), one of the biggest natural enemies is the brown-headed cowbird, a brood parasite. Cowbirds search out nests of other species and lay their eggs for the host species to raise. They will wait for the female of the host to lay her first egg. When the potential host has left to forage, the female cowbird will remove the egg and lay one of her own. Many bird species do not recognize their own eggs. Cowbird eggs tend to hatch 1 or 2 days earlier than the warbler or vireo eggs. This gives the baby cowbird a big jump on the other species in both size and noisiness. Cowbirds do not specialize or target particular host species. There is no egg mimicry or mouth mimicry as there is in the common cuckoo or some estrildid brood parasites that specialize on a single species each. Cowbirds will lay their eggs in any nest they find. With the impartiality of a roulette wheel, the cowbird distributes its eggs. The probability that a nest will get cowbird attention depends on the number of cowbirds laying eggs in the area and the number of host nests available. Thus, the cowbird's effect on a vulnerable host like the GCW or BCV is particularly insidious since it is unrelenting even though the host species is vanishing. The cowbird is not deterred by the scarcity of one host. The very last nest of a vanishing species is just as likely to be used as the nest of a plentiful species. From the cowbird's point of view, it is a simple numbers game. Lay enough eggs in enough different nests and you are bound to get your genes into the next generation. Although some species like the gray catbird and yellow warbler have evolved strategies against the cowbird, most deep-forest species have not. GCWs can raise one of their own chicks if there is only one cowbird egg. BCVs are always doomed to nest failure should even one cowbird egg be laid in their nest. With GCWs, abandonment of first clutches, or raising cowbird young in addition to one of their own, still decreases the total number and survivability of GCW young produced.

Feral, domestic, and stray cats associated with suburban and urban areas play havoc with all types of songbirds including the GCW. Again, losses are more devastating to species that are already in decline.

Foraging: Oaks are especially important as foraging trees. Moist canyon bottoms, draws, creeks, and cool wooded slopes support best food source. Cattle should be excluded to improve GCW foraging. A woodland buffer of approximately 300 ft (91.5 m) should b established around identified habitat.

Nesting: GCW is the only species to require mature ash juniper with hardwoods in their nesting habitat. Nests require junipers 5 to 32 feet tall, with an average of 15 feet. In addition, older juniper bark is required for making nests; trees must be at least 20 to 30 years old.

Migration: The GCW migrates to Mexico along a narrow montane (above 1300 m) pine or pine-oak association in the Sierra Madre Oriental cloud forest that is not under control of the ESA standards. Temporal residence in the United States is only from mid-March to July … less than 5 months. Nesting and habitat season when they are in the United States are the same.

Required Acres: The GCW requires a territory from 3 to 6 acres, smaller in better habitat. The GCW is a somewhat social species with nest groups of fewer than 6 pairs. A minimum of 50 acres (20 ha) is required. Individuals tend to stay within about 220 meters of their previous nest, so there is little dispersal (maximum was 3.5 km).

Comment: Although the ESA applies to the United States and federal lands, the GCW again shows the need to look well beyond the boundary of any public land. Its status cannot be improved without international cooperation because it migrates to Mexico along a narrow path that is also suffering due to land use conversion from natural land to urban, pasture, and commercial uses. Thus, the best management practices by the military may make no difference if the procedures are not a piece that fits successfully into a much larger, international puzzle. Again, a more comprehensive view of the species is a requirement for its continued survival.

Data Currently Available to Support Modeling GCW Over Large Regions:
1. Use 30-m resolution *National Land Cover Data (NLCD)* to model large tracts of mixed deciduous and coniferous tree cover.
2. National Elevation Data: at 1, 1/3, (and 1/9 where available) arc-second resolution to determine steep canyon slopes for prime GCW habitat.
3. *Soil Survey Geographic DB (SSURGO)* for high surface runoff.
4. U.S. Census block population counts for population density.
5. National Elevation Data: at 1, 1/3, (and 1/9 where available) arc-second resolution to determine flat and rolling hills.

A model of brown-headed cowbird habitat would be useful for determining GCW impacts.

*Species Profile for Black-capped Vireo (***Vireo atricapillus***)*

Brief Life History: Black-capped vireo (BCV) habitat loss is due to urbanization, browsing by herbivores, brush clearing, and natural succession. Brood parasitism by the brown-headed cowbird is a major cause of reduced populations. The BCV's preferred habitat consists of scattered trees and numerous dense clumps of shrubs growing to ground level, interspersed with open areas of bare ground, rock, or grasses. Foliage that extends to ground level is the most important requirement for nesting. Plant species commonly used as nest substrate are evergreen, sumac, and shin oak. BCV territories can be located on level terrain or on slopes ranging from ravines to the sides of arroyos. On level terrain, BCV habitat tends to change through succession, from prairie grass to oak-juniper woodlands. BCV habitat in level areas was maintained by wildfires that kept the vegetation in an early successional stage. Total cover has been found to range from 17 to 88 percent.

Habitat: The BCV prefers rugged terrains of steep slopes, such as heads of ravines or along the sides of arroyos in sustained, clumped, mixed deciduous/evergreen shrubland vegetation. They like scattered trees and numerous dense clumps of shrubs (cover from 17 to 88 percent) growing to ground level, interspersed with open areas of bare ground, rock, grasses, or forbs. Typically, this wider variety of cover types occurs in drier areas. Vireos avoid patches with trees over 40 feet high. On level ground, the habitat tends to change through succession, from prairie grass to oak-juniper woodlands but is maintained by occasional wildfires. Habitat losses occur due to urbanization, browsing by herbivores, brush clearing, and natural succession. Urbanization increases predation. Cattle grazing has multiple negative impacts. Corridors of disturbance (e.g., roads) increase habitat fragmentation. Increasing fragmentation in habitat patches (measured in patches separated by kilometers) decreases the probability of successful dispersal between these patches and increases the potential for nest predators from nearby nonhabitat. Therefore, areas that have less habitat edge and are a greater distance from the edge provide better habitat quality.

Habitat Maintenance: Habitat is maintained in an early successional stage by wildfires and naturally occurring grazing animals. Natural condition consists of a mosaic of habitats, a proportion of which will be a stage suitable for vireos. It is essential to preserve/enhance areas of naturally low woody vegetation. Areas that are a greater distance from undesirable land uses (urban development, pasture, timbering, agriculture) provide greater viability potential; less fragmentation is better.

Foraging: If the habitat is available, food sources will be present, so focusing on adequate habitat is the primary concern.

Nesting: When the BCV is in the United States, it is in nesting terrotiry; otherwise it winters in Mexico. This bird nests in spatially heterogeneous clumps of woody deciduous (oak) vegetation (35 to 55 percent dispersed cover) separated by bare ground, rocks, and/or herbaceous vegetation and avoids densities of junipers higher than 10 percent. Foliage that extends to ground level is the most important requirement for nesting. Most nests are located between 0.4 and 1.24 meters above ground level and are well-screened by foliage.

Migration: The BCV breeds in summer from central Oklahoma south through the Edward's Plateau and Big Bend National Park, Texas, to central Coahuila, Mexico. The bird winters in central Coahuila, Mexico. Temporal residence in the United States is for breeding during the months of April through August. Nesting and habitat in the United States are the same.

Required Acres: Vireos avoid otherwise suitable patches of habitat if the patches are less than 50 ha in size. A single viable breeding population consists of at least 500 to 1,000 breeding pairs.

Comment: The vireo and warbler, both TES, occupy the same disappearing habitat, but at different successional stages. This TES pair makes an excellent example of the effectiveness of managing healthy ecosystems rather than focusing on a single species. Again, this is why regional landscape ecology provides a more effective means of managing TES.

Data Currently Available to Support Modeling BCV Over Large Regions:
1. Use 30-m resolution *National Land Cover Data* to model deciduous forest.
2. National Elevation Data: at 1, 1/3, (and 1/9 where available) arc-second resolution to determine rough and level terrain for differing BCV habitat.
3. U.S. Census block population counts for population density.

*Species Profile for Indiana Bat (*Myotis sodalis*)*

Brief Life History: Generalizations with which Indiana bat (IB) summer habitat is described indicate that almost any hardwood forest near a body of water has potential to be used as a summer habitat. Alternatively, it means we do not know much about what determines suitable habitat. The eastern third of the United States is possible habitat for IB. The following caves have been designated as Critical Habitat within the Southeast Region: White Oak Blowhole Cave in Blount County Tennessee; Bat Cave in Carter County, Kentucky; and Coach Cave in Edmonson County, Kentucky.

Habitat

Winter: The limiting factor for this TES is the 6-month winter hibernacula. The major sites consist of a few limestone caves in Kentucky and Tennessee that are critical. Although suitable caves may be available, they may not be used. For this reason, modeling may be of little value for the IB. Since no hibernacula are known on military reservations, it is clear that successful protection and recovery of this species is an issue larger than the military can handle alone. Many small hibernacula are known across the bat's range, but many appear to be abandoned or have much decreased overwintering numbers. There is a definite breeding period that usually occurs during the first 10 days of October near hibernation caves. Males forage near the cave and roost less than 6 km from hibernacula in dead trees on upper slopes and ridge tops. Hibernation occurs between October and March in clusters of many thousand bats. Caves in midwinter average 37 to 43 degrees Fahrenheit, with a relative humidity of 87 percent and have pools of water.

Summer: The summer habitat for the Indian bat is potentially any hardwood area near open water (rather than a small stream). However, a few of the characteristics that are attractive to the bats are as follows:

- Avoidance for a distance from paved or well traveled roads,
- Closed canopy with crown height of about 65 feet,
- Diameter Breast Height (dbh) of dominant overstory species of 46.7 cm (18.4 in.) for living roost trees and 35.6 cm (14.0 in.) for dead roost trees,
- Forest/habitat type of hardwood overstory stands (i.e., floodplain, bottomland, riparian, and mixed upland stand types),
- Species composition of the understory of sugar maple, silver maple, box elder, hackberry, slippery elm, sycamore, American elm, black walnut, eastern redbud, and American basswood,
- Species composition of herbaceous vegetation of poison ivy, various grasses (genera not specified), jewelweed, stinging nettle, Virginia creeper, and wild grape), and
- Presence of preferred tree species for use as potential roost trees.

Habitat Maintenance

Winter: Cave tourism and vandalism contribute to the bats becoming endangered.

Summer: Since Indiana bats tend to nest in dead trees and snags, it is important not to cut down those that are present.

Foraging: The IB forages within 1 mile of roost for insects in the upper canopy (20 to 30 m) of riparian/bottomland stands. Stands with a mean height of 19.8 m (65.0 ft) represent preferred conditions. The IB has a preference for more mature, closed canopy stands with large-diameter trees. Females and juveniles forage in the airspace 2 to 30 m above a stream and a linear distance of 0.8 km; foraging density was 17 to 29 bats/ha near the foliage of riparian and floodplain trees. Males forage the densely wooded area at tree top height.

Roosting: The IB roosts in riparian and floodplain forests as well as in upland regions with a closed to moderately closed canopy (100 to 30 percent). More attractive are locations where trees have high percentages of loose or peeling bark. Trees with about 25 percent coverage of loose, sloughing bark are best (e.g., older dead trees or hickory species). Trees in sunny openings are attractive because they are warmer. Births occur in June in very small, widely scattered colonies consisting of about 25 females. There are 1 to 3 primary roosts per colony. One reproductively active colony occupied eight different roost trees (all green ash). About 25 to 37 days are required for the development of flight and independent feeding in the young. This occurs in July or August.

Migration: Migration to the wintering caves usually begins in August. By late November most IB are in hibernation.

Required Acres: The IB requires a minimum of a 1/2-acre cluster of snags and older trees.

Comment: Bats are nocturnal, yet there is almost no research on the effects of night lights in fragmenting their habitat. Light fragmentation may contribute to the bat's TES status, but diurnal biologists have not yet focused on the fact that the resource of darkness is as much a part of a habitat niche as is loose or peeling bark. To illustrate this point, there is variation in how much loose or peeling bark is needed, but there is no variation in the fact that all of these bats forage only at night; yet the literature emphasizes the former and does not even mention the latter.

Data Currently Available to Support Modeling IB Over Large Regions:

1. Use 30-m resolution *National Land Cover Data (NLCD)* to model transportation corridors from caves to water.
2. Use 30-m resolution *NLCD* and *TIGER* files to locate large bodies of water.
3. EPA STORET: Water quality reports for large rivers and lakes.

Species Profile – Gray Bat (Myotis grisescens)

Brief Life History: Little is known about gray bat (GB) feeding habits. Limited observations indicate that the majority of insects eaten by GB are aquatic species, particularly mayflies. The GB foraging habitat is restricted by the bat's dependence on major areas of water. A direct correlation exists between the distribution of summer colonies and bodies of water. Water quality is important for the production of aquatic insects. GB food sources can be reduced by channelization, siltation, and herbicide application. Land near water should be forested to provide protective cover during flight from the caves to the food supply. The GB prefers caves that are within 1 km of a major river or lake, and they are rarely found in caves located at distances greater than 4 km.

Habitat: The GB has highly specific roost and habitat requirements; fewer than 5 percent of available caves are suitable. Distribution has always been patchy, but fragmentation and isolation are now enhanced.

Winter: Beginning in early fall the GB roosts in deep and vertical caves having a temperature of 6 to 11 degrees Centigrade. Caves with a large volume that trap cold air but which preserve good airflow are preferred. Roughly a dozen caves are used for over-wintering by most gray bats, with one location accounting for more than half the total.

Summer: Caves and sinkholes in karst limestone may support summer habitat, which is restricted by the bat's dependence upon major areas of water where flying insects are abundant. Maternity colony caves should be within 1 km (0.6 mile) of a major river or lake but always less than 4 km. The GB prefers maternity caves that are warm and tend to capture the metabolic heat from a large number of clustered individuals in small chambers, with temperatures that range from 14 to 25 degrees C (57 to 77 degrees F). Sometimes storm drains and concrete culverts with high humidity and running water without sewage have been identified as have been occupied. A direct correlation exists between the distribution of summer colonies and bodies of water (e.g., open water, stream banks, lakes, or reservoirs).

Habitat Maintenance

Winter: It is essential to preserve critical overwintering caves.

Summer: Maintain the habitat associated with foraging activities, particularly good water. Avoid cave tourism and keep human activity away from near caves. Disturbance of a maternity colony may cause thousands of young to be dropped to the cave floor where they perish. Forested corridors, river edges, and reservoir shorelines should be left intact within 25 km of summer caves, and the vegetation surrounding cave entrances should be maintained. Avoid deforestation (which leads to increased bat predation.), chemical contamination, and impoundment of waterways.

Foraging: Forested areas surrounding caves or located between caves and feeding habitat with a good canopy to travel though are the best areas for foraging. These areas must be near a water source, specifically along or near rivers or lake/reservoir shores. All riparian areas used, but larger areas are better. Foraging quality decreases by the distance from roost to over water foraging. Any wide riparian tree corridors are desirable between roost and water areas. A wider riparian corridor is most desirable if it is less than a kilometer from cave, and mostly limited to being within 4 km, though the bats can range up to roughly 25 km. Foraging habitat is not affected by human activities except clearing, channelization, siltation, and herbicide application.

Roosting: Reproductive season for the GB is in May or June on the summer range. Weaning takes 2 months and the young are volant in August.

Migration: Migration between winter and summer caves range from 10 to over 200 miles. Migration to the wintering caves usually begins in August. By late November most GB are in hibernation.

Required Acres: The GB requires areas distant from human activities/occupation. They need a cave large enough to hold thousands of pregnant females. Males stay in smaller cave colonies.

Comment: Three of the 7 high-priority Army TES, including the gray bat, are nocturnal. However, the literature hardly mentions this and almost no mention is made of the effects of human (Army) night lighting on their habitat, foraging, or ciability. Much more research needs to be done on nocturnal TES.

Data Currently Available to Support Modeling GB Over Large Regions:
1. Use 30-m resolution *National Land Cover Data (NLCD)* to find forests model transportation corridors from caves to water.
2. Use 30-m resolution *NLCD* and *TIGER* files to locate large bodies of water.
3. EPA STORET for water quality reports for large rivers and lakes.

*Species Profile for Lesser Long-nosed (Sanborn's) Bat (*Leptonycteris curasoae yerbabuenae*)*

Brief Life History: Lesser long-nosed bats (LLB) are found in Arizona from the Picacho Mountains south and west to the Agua Dulces, and south and east to the Chiricahuas, and into Mexico. They are also found in southwestern New Mexico, Baja California, and well into Central America. LLB summer habitat is in the United States and their winter habitat is in Mexico. LLB are found between 900m and 1500m elevations, in rough terrain providing either food (primarily Palmer's agave) or shelter (primarily caves and abandoned mines). The flowers of Palmer's agave are the primary LLB high-energy food. Other species of agave and several cacti, including the giant saguaro, provide pollen, nectar, soft pulp, and, occasionally, fruits, making up the diet of the LLB. Range fires caused by excess growth of invasive grasses, such as *Bromus* and Lehmann lovegrass, may affect the success of Palmer's agave. A decrease of Palmer's agave may be a cause of colony abandonment. The LLB is a seasonal resident in Arizona, usually arriving in early April and leaving from mid-September to early October. It resides in New Mexico only from mid-July to early September. LLB time their movement and feeding to the progression of flowering associated with the cacti and agaves. Many species of columnar cacti and agaves appear to provide a "nectar corridor" for lesser long-nosed bats in spring and fall as they migrate between Central America and Mexico in the south and places as far north as southern Arizona. Agaves are perennial succulents. Agave seeds germinate readily with adequate moisture, typically in open areas with limited competition from other plants. Unfortunately, Palmer's agave has been studied almost exclusively in cultivation. Ecology of the LLB is poorly understood. Palmer's agave is relatively slow growing, often taking 20 or more years before initiating the single reproductive event in its life. A flowering stalk erupts from the rosette of a mature plant, growing rapidly through the spring and early summer. It is unknown how fire frequency and intensity, which are influenced in part by livestock grazing, affects agave populations. In the absence of frequent ground fires, agave populations could potentially benefit due to reduced mortality resulting from fire. However, infrequent intense fires could kill greater percentages of agaves if they are growing amid brush or other areas of high fuel loads.

Habitat: The LLB is nocturnal.

Winter: The LLB is threatened by agave harvests in Mexico for the liquor industry (tequila).

Summer: In this species, the coverage of habitat and foraging are the same, although they are indicated separately in this section. LLB habitat can be any rough terrain, particularly canyons and nearby areas providing food (primarily the flowers of Palmer's agave) or shelter (caves and abandoned mines) between 900 and 1500m with an upper limit of 1725m. During April through July the bats are at elevations below 3,500 feet and from July to late September or October up to 5,500 feet. Desert scrub areas of short grass plains, sactan grassland, sycamore, cottonwood, rabbitbrush, and oak savanna including lower edges of oak woodlands are viable habitat for LLB. Although many bats exist, there are few available large roost caves. These rost caves are threatened by human disturbance from activities as cave exploration.

Habitat Maintenance

Winter: In Mexico, Palmer's agave is used to make tequila. Protection of agave from harvest for tequila will preserve the LLB's winter habitat.

Summer: Limit grazing to less than 40 percent of land level to preserve a healthy ecosystem. Livestock and deer may feed on agave stalks prior to flowering. Since the Palmer's agave takes many years to reach maturity and flowers only once before dying, the result of grazing make take decades to have an effect. Native ungulates have a similar impact. And saguaro cactus seedlings need shade from nurse plants that also may be destroyed by grazing. Grazing impacts can be expected to be greater near water and less on steep slopes. Invasive grasses, particularly Lehmann lovegrass, burn hot fires that kill agave seedlings; encourage native grasses for cooler natural burns. Limit off-road vehicle usage or other human disturbance such as caving.

Foraging: It is critical that concentrations of food are available. The main seasonal food is nectar from the Palmer's agave, which blooms from July to September on rocky slopes and hilltops at 900 to 1,800 m. The LLB also uses Parry's agave, desert agave, amole, saguaro, and organ pipe flower nectar and pollen. It forages in areas of saguaro (blooming in April/May), agave (blooming April through July), ocotillo, palo verde, and prickly pear. Often the LLB forages in flocks. Larger colonies tend to forage to greater distances. Each night the roost to foraging distances (one-way) range from 25 km to 100 km. Therefore, destruction of food plants many kilometers from an LLB roost could have a negative impact.

Roosting: During the day the LLB roosts in caves, mine tunnels, and occasionally old buildings at low elevations near concentrations of flowering columnar cacti. The bat is colonial only from April to the end of July. During August they move to higher elevations (up to 6000 ft) near blooming paniculate agaves.

Migration: The LLB is migratory from southern Arizona and extreme southwestern New Mexico, through western Mexico, and south to El Salvador. Migration routes need good foraging for large numbers of bats. The bat is present in the United States for 6 months from early April to early October. Movement between Mexico and the United States and within the United States is based on progression of cacti and agave flowering.

Required Acres: Large flight distances require habitat evaluation at the landscape level rather than being limited to a few acres.

Comment: Given the ability of the bat to move freely and widely across the landscape, large landscape scale analysis is more meaningful in assessing potential impacts to its foraging habitat.

Comment: More research needs to be done on nocturnal TES.

Data Currently Available to Support Modeling LLB Over Large Regions:
1. Use 30-m resolution *National Land Cover Data* to model shrub cover and nectar corridors to Mexico.
2. National Elevation Data: at 1, 1/3, (and 1/9 where available) arc-second resolution to determine rough terrain and elevations between 900m and 1500m for prime LLB habitat.
3. U.S. Census block population counts for population density.

Summary

Once it has been determined that an installation will manage land for TES habitat preservation and population recovery, two questions must be answered. The first is: "Are these lands the best habitat for these TES?" The second is: "Can adequate habitat be found beyond the installation boundaries to support the needs of the TES in question?" Through the ACUB program, the Army now has the capability to provide some support to maintain important habitat near installation lands. Through this program, the Army can move some of its TES responsibility from its training lands to areas off the installation that will be managed by agencies and organizations whose missions more closely relate to TES habitat preservation.

We have seen how the development of regulations and management plans in combination with research efforts by the Department of the Army are aimed at accomplishing good management for TES. Although many different species inhabit or visit different installations, the Army has identified its top seven TES of concern and is aiming a great deal of its research and management funding toward these species.

From the evaluations of the TES life histories presented in this chapter, a few clear conclusions can be formulated.

- Complete data to define the habitat often are not yet available, so the usual implication is that the data needed to do landscape scale modeling and monitoring will be incomplete.
- Landscape-scale evaluations can easily be carried out on some, but not necessarily all, of the most critical concerns for these TES and these evaluations can provide helpful management and policy direction.
- Landscape-scale modeling may be inappropriate for some characteristics of the species. Even if the habitat requirements were known, we would still need to find supporting data. This data also often does not exist and would be difficult to derive even from (or particularly from) remote sensing/satellite imagery (e.g., you cannot use remote sensing to identify bat roosting caves).
- For all of the species, their habitats extend well beyond installation boundaries. Therefore, management of the species must extend beyond installation boundaries and be in cooperation with other local agencies and stakeholders.
- None of these TES respect legal or political boundaries. Avian TES fly across state boundaries and the TES bats share areas of habitat in both the United States and Mexico. The point of this observation is, no matter how well a particular installation or group of installations managed the lands and recovery of the TES, this effort will not be of sufficient value if their entire habitat is not taken into consideration independent of ownership or international boundaries. Thus, a call for greater cooperation between agencies within and adjacent to the borders of the United States is a requirement.

- Since most species must be managed/modeled at the landscape scale, the idea that an individual installation has the ability to recover a species puts too much responsibility at the wrong administrative level. For example, if the limiting factor for a species is a cave located off the installation, even the best Army management practices will be for naught if the TES are not allowed to use the cave. Installation managers are justified to ask for cooperation and support from other governmental agencies, including those at higher administrative levels.
- All species response to a healthy (or degraded) ecosystem. Species such as TES where the munbers are declining dramatically, are a symptom of the problem of degraded ecosystems. As Chapter 2 makes clear, the solution lies at the landscape scale.
- Time is not on the side of these TES. We do not have the luxury of waiting to know everything about the habitat before we must start managing and modeling at the landscape scale.
- The benefits of healthy ecosystems (ecoregions or landscapes) flow through the entire matrix to benefit both the natural and man-made landscape.
- In some cases the local TES have conflicting requirements. For example the golden-cheeked warbler and the black-capped vireo both inhabit the same location but within that location each species inhabits at different vegetation successional stages. Another example is the red-cockaded woodpecker that uses the sap of nearly dead longleaf pine trees to protect its eggs from being eaten by the indigo snake, another species of high concern. These examples suggest that the available natural land must be managed such that the entire ecosystem can also work. When an ecosystem becomes so fragmented that only portions of it at particular stages of their lifecycles can be preserved, conflicts can emerge that require conflicting management actions. Once again, this suggests that for TES management to be successful, it must include areas beyond installation boundaries, must be at a regional scale, and must be carried out in cooperation with agencies and stakeholders with like interests.
- Managers and researchers need to think of darkness as a habitat resource for nocturnal animals. Just as the cutting of the longleaf pines in the eastern United States decreased habitat for the red-cockaded woodpecker, it may well be that increased use of night lighting decreases the available period of darkness. Darkness can be considered a resource for nocturnal animals. In terms of habitat fragmentation, the placement of a series of lights in a new residential area or along a highway may present a barrier as effective to night foraging or migration as the loss of the vegetation. The literature contains very little research on the question of nocturnal habitat fragmentation due to nightlights. For roughly half of the Army list of TES species (or any list of species for that matter) it may well be that night lighting is a habitat fragmentation

issue as much as the availability of tree cover. This issue needs to be researched.

Most of these individual items lends support to the need to look at TES species at a regional or landscape scale, and in broader terms than have traditionally been accomplished. At the same time we need to focus on those TES characteristics that can be identified and translated into useful modeling procedures that can support actual land management directions. A sense that emerges from a review of life histories of the TES is that although a lot is known about the species, it is not sufficient for directing the management of the lands they inhabit. Thus, it is suggested that the research be directed more toward investigations that provide information directly useful to land managers as opposed to investigations that provide additional interesting characteristics of the species. The direction of future research will become more clearly defined after the review of research that resulted from the population viability analysis in Chapter 5.

4 Identifying TES Migration Corridors

Tom Hoctor, Crystal Goodison, William W. Hargrove, Forrest M. Hoffman, Robert C. Lozar, and Winifred Rose

Introduction

To assess the problem of habitat fragmentation, it is necessary to identifiy the remaining corridors that are available to the species for foraging and migration. This chapter presents a review of the methods used to identify TES migration corridors and provides examples.

The first nationwide effort toward identifying migration corridors was the GAP Analysis sponsored by the National Biological Service (see GAP Analysis, page 18 in Chapter 2). Although the impact of GAP Analysis is not to be diminished, several shortcomings (e.g., done by states at different times using different criteria) have suggested that better approaches need to be adapted. The following paragraphs present reviews of two emerging candidates: (1) the Southeast Ecological Framework (SEF) and (2) the Corridor Tool.

The Southeast Ecological Framework

Description

The EPA is supporting an effort to identify critical existing natural lands and corridors in the United States to provide the greatest preservation value yet available. As an Army-specific subset of this initiative, a report done for the Engineer Research and Development Center's Construction Engineering Research Laboratory (ERDC-CERL) in 2003, the authors described the overall initiative as follows:

> The Southeastern Ecological Framework (SEF) is a decision support tool created through systematic landscape analysis of ecological significance and the identification of critical landscape linkages in a way that can be replicated, enhanced with new data, and applied at different scales. It is intended to provide a foundation for the adoption and implementation of effective and efficient conservation measures to minimize environmental degradation and protect important

ecosystem services. It has been developed for all eight southeastern states contained within the boundaries of the Environmental Protection Agency Region 4: Florida, Georgia, South Carolina, North Carolina, Alabama, Mississippi, Tennessee and Kentucky by staff of the Planning and Analysis Branch of EPA Region 4 and researchers at the University of Florida. Work on the project began in October 1998 and was completed in December 2001.

The identification of linked regional networks of lands critical for conserving natural resources is a key strategy for applying landscape ecology principles in planning efforts to avoid and minimize the degradation of ecological integrity caused by habitat fragmentation. By identifying a large scale, regional conservation framework, it is possible to provide a foundation in which protection of the important ecological properties and processes can be optimized for multiple benefits at local and regional scales (Harris et al. 1996; Noss and Harris 1986).] Trends in regional conservation during the past 5 years have moved toward regional approaches to natural resource protection in an attempt to address issues of scale and complexity. Many organizations such as the World Wildlife Fund and The Nature Conservancy are attempting to develop geographical information system tools for identifying biodiversity hot spots and other priority areas to better facilitate effective conservation.

The Southeastern Ecological Framework represents a similar strategy to identify areas of natural resource conservation significance at a regional scale. The SEF is a first iteration of a region-wide assessment of areas critical for conserving natural resources including important ecological services and biodiversity that will help promote the need for regional conservation assessments and planning and will continue to be improved as more data and assessment techniques are developed in the future.

One of the primary objectives of the SEF is to develop partnerships with federal and state agencies and other groups to more effectively conserve natural resources through cooperative planning, land protection, and management. The Department of Defense has numerous installations in the southeastern United States. … [U]rban growth is a problem throughout much of the region, and urban encroachment can threaten the military mission of Department of Defense installations. Therefore, protection of land around these military installations that can provide additional habitat for federally listed species and other species of conservation interest to support viable populations while providing buffers for military training activities is an important goal. Regional ecological assessments like the SEF can be used as part of a process to determine areas that are most significant for conservation outside military installations. Furthermore, the SEF presents the opportunity of cooperating with EPA and other Federal,

> State, and NGO's in directing combined resources to implementing a regional approach to habitat preservation that will greatly benefit both biodiversity conservation and the military mission of these installations.[56]

One of the issues that the SEF had to handle was the need to be consistent among several states as much as possible. Although the precursor of the SEF was a study done specifically for the State of Florida, the criteria for the expanded SEF attempted to represent the best efforts of the several member states included in the SEF, as represented in Table 4-1 for the initial identification of the major areas, the Significant Ecological Areas (SEAs).[57]

Table 4-1. Criteria for selecting significant ecological areas for the Southeastern Ecological Framework.

Data layer	Priority Area Criterion	States in which criterion used	Explanation/Rationale
Areas of high habitat diversity	Areas that have 4 different habitat types within a 27x27 neighborhood using 90-meter pixels and NLCD landcover/landuse data.	All states	Diverse habitats have the potential to support a wide range of flora and fauna, viewed as consistent with project goals. Based on iterative comparisons, areas with 4 different habitat types using NLCD appeared to be a useful additional indicator of areas with significant habitat diversity.
Potential black bear habitat	NLCD forest, not within ½ mile of Class 1 roads, road density of less than 2 miles per sq. mile AND greater than or equal to 10000 acres within 100-140 kilometers of occupied bear habitat.	All states	Black bears are a useful umbrella species for identifying large areas of relatively intact habitat that may be important for many other species of conservation interest. The SEA zone is farther from occupied bear habitat.
Roadless areas	Areas 2500 to 5000 acres with no roads (excluding large water bodies) of any kind based on 1990 TIGER roads.	All states	Roadless areas, important to species sensitive to humans, are typically buffered from disturbance and provide connectivity for species isolated by roads. The SEA threshold was based on recommendations by reviewers.

[56] Hoctor, Thomas D. and Crystal Goodison, *Defining The Southeastern Ecological Framework For Military Installations*, Geoplan Center, Department of Landscape Architecture Department of Urban and Regional Planning, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida, September 2003.

[57] Carr, Margaret H., Thomas D. Hoctor, Crystal Goodison, Paul D. Zwick, Jessica Green, Patricia Hernandez, Christine McCain, Jason Teisinger, and Karen Whitney, *Southeastern Ecological Framework,* The GeoPlan Center, Department of Landscape Architecture Department of Urban and Regional Planning, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida, May 2002.

Data layer	Priority Area Criterion	States in which criterion used	Explanation/Rationale
Areas with high stream start reach densities	Defined as areas in the top 10% in stream start reach densities with forest cover within each ecoregion. EPA Region for is broken into various ecoregions (such as Southeastern Coastal Plain , Blue Ridge Mountains, etc.) based on geology, soils, climate, etc. These ecoregions were used as a unit of analysis for any factor that might vary significantly among ecoregions.	All states	Areas with high stream start reach densities represent areas that influence multiple watersheds, that are potentially relatively steep and thus vulnerable to erosion and that have the potential to harbor and protect aquatic biodiversity and water quality downstream. The SEA criterion is based on ecoregions, which allows for the identification of high stream reach densities within all ecoregions in the region.
Significant riparian areas	NLCD wetlands adjacent to streams (within 180 meters), intact riparian vegetation adjacent to streams (delineated as pixels with 75% density of natural/semi-natural landcover in a 5x5 neighborhood within a 180m stream buffer), and 100-year FEMA floodplains (where data was available).	All states	Riparian resources were one of the primary focal resources within the model. These various data sources and analyses delineate riparian areas of significance. NLCD wetlands are a more liberal identification of wetlands than contained in the PEA wetland analysis, intact riparian vegetation is important for water quality and wildlife habitat and corridors, and 100 year floodplains are important for flood control, functional ecological processes, etc.
FNAI[a] Potential Natural Areas (PNAs)	Priority level 3 through 5 areas from the Florida statewide inventory of potentially significant natural areas.	Florida	Includes most of the remaining sites available to conserve native ecosystems in Florida, though some disturbance may be present and status of tracked species may not be completely known.
FWC[b] Vertebrate Species Hotspots	Based on FWC recommendations, areas supporting potential habitat for 6-9 focal vertebrate species.	Florida	Data set was created by adding together potential habitat maps for over 100 vertebrate focal species. The original dataset consisted of values 1-26. Areas with 6-9 or more species indicate significant areas of overlap in habitat for species of conservation interest.
North Carolina Significant Natural Heritage Areas	Significant natural areas ranked C in a statewide inventory.	North Carolina	Areas supporting significant natural communities and species of conservation interest considered to be of regional significance within North Carolina.

b Florida Natural Areas - Florida Natural Areas Inventory as described in Cox, J., R. Kautz, M. MacLaughlin, and T. Gilbert. 1994. Closing the gaps in Florida’s wildlife habitat conservation system: recommendations to meet minimum conser-vation goals for declining wildlife species and rare plant and animal communities. Florida Game and Fresh Wa-ter Fish Commission, Tallahassee Florida.

b The Florida Fish and Wildlife Conservation Commission was previously named the Florida Game and Fresh Water Fish Commission.

Connecting or "linkage" areas between significant SEAs was established based on:

1. Riparian linkages including all major river systems and coastal water bodies such as lagoons and connected estuaries.
2. Upland linkages (used primarily in mountain and plateau ecoregions).
3. General hub-to-hub linkages (considers wetlands and uplands as potentially suitable and was used primarily in the Coastal Plain and Piedmont ecoregions).

Although considerably more involved than outlined here, the SEF established important concentrations (hub areas) of significant natural lands and connections between them (Figure 4-1). Basically, the SEF is a series of hubs with connecting corridors of significant natural lands.

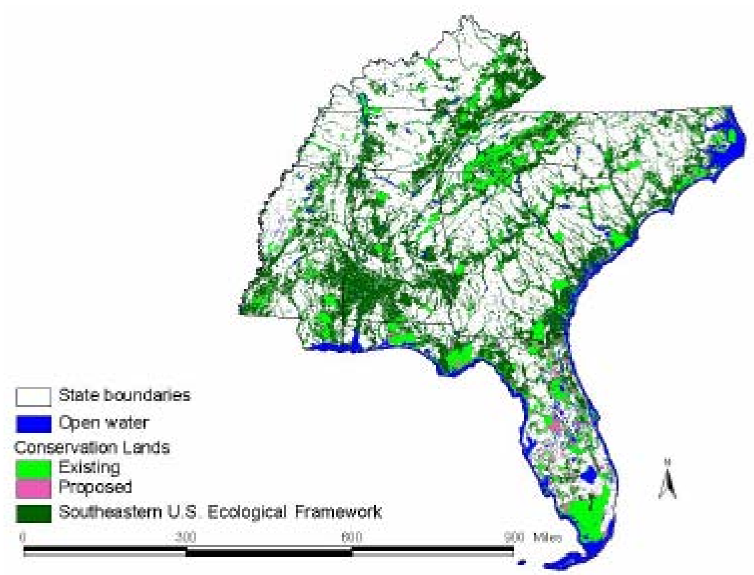

Figure 4-1. The Southeastern Ecological Framework for EPA Region 4 including existing conservation lands for all states and officially proposed conservation land projects in Florida.

The SEF and Military Installations

The issue of how this relates to TES at military installations was addressed in a 2003 study (Hoctor and Goodison 2003[58]). The purpose of the study was to relate the SEF to

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58 Hoctor, Thomas D. and Crystal Goodison, *Defining The Southeastern Ecological Framework For Military Installations*, Geoplan Center, Department of Landscape Architecture Department of Urban and Regional Planning, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida, September 2003.

lands of ecological significance around selected DoD and Department of Energy (DoE) installations. The installations included in the study are shown in Figure 4-2.

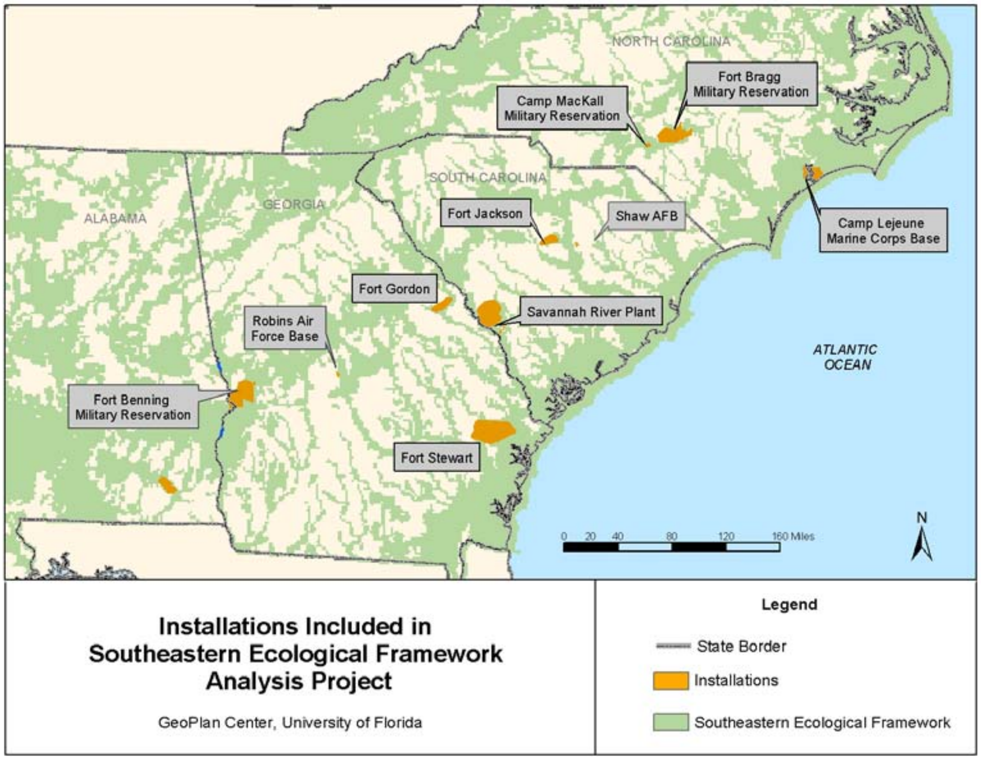

Figure 4-2. Installations included in Southeastern Ecological Framework analysis project.

Fort Bragg Example

For the purpose of the current report, we will see how the University of Florida study relates to an example installation, Fort Bragg, NC. Figure 4-3 shows the installation, the SEF, a boundary (red) that represents a logical study area for the installation (largely based on hydrology; see the original report [Hoctor and Goodison 2003[59]] for details), a 5-mile buffer around the installation, and significant nearby conservation lands. Characteristics of the nearby lands are summarized in Table 4-2.

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59 Hoctor, Thomas D. and Crystal Goodison, *Defining The Southeastern Ecological Framework For Military Installations*, Geoplan Center, Department of Landscape Architecture Department of Urban and Regional Planning, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida, September 2003.

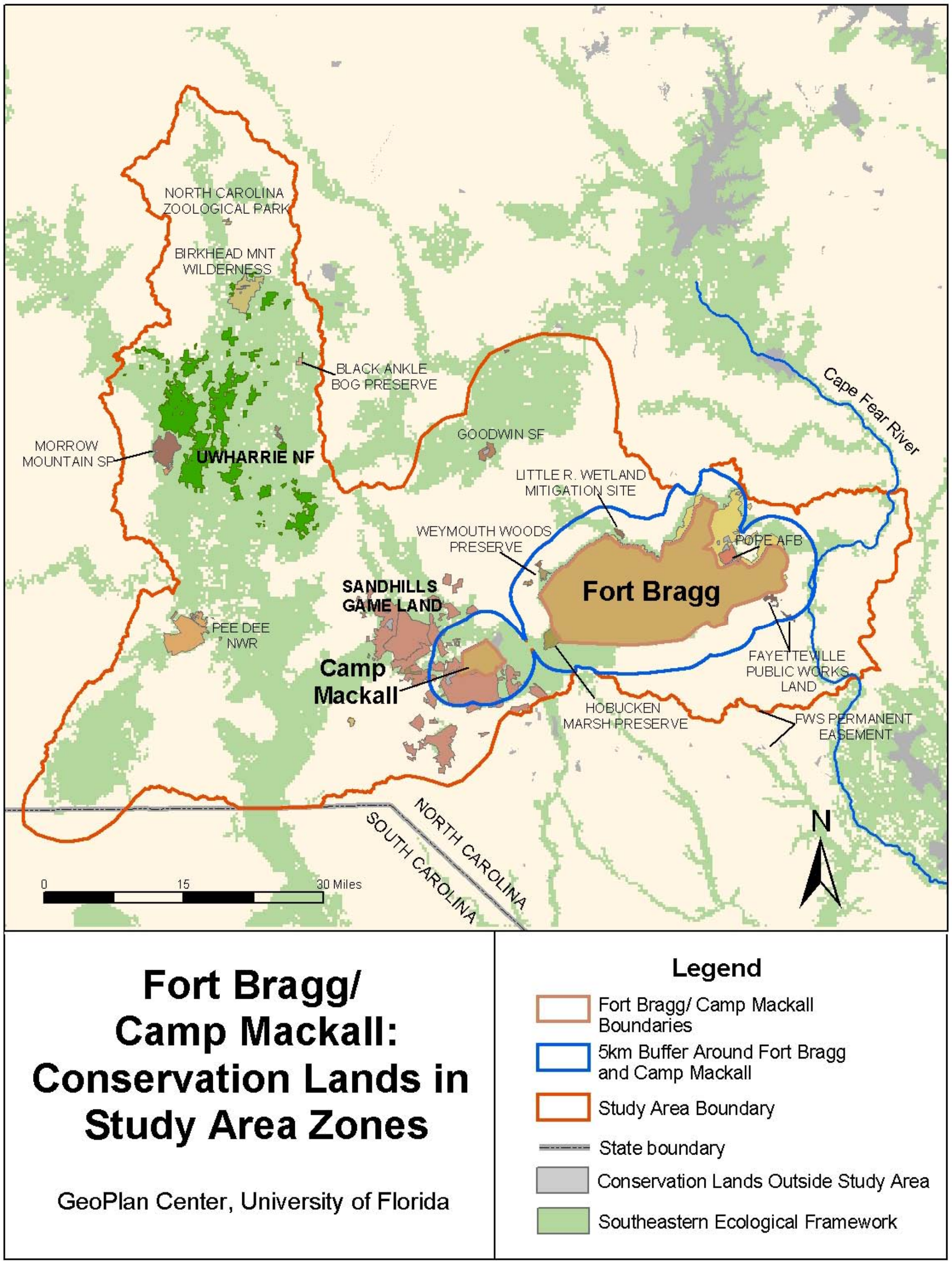

Figure 4-3. Summary of SEF and significant lands near Fort Bragg.

Table 4-2. Conservation lands in Fort Bragg/Camp Mackall study area.

Name of Conservation Land	Acreage of Conservation Lands Within Study Area			Manager
	W/in 5-km Buffer	Outside 5-km Buffer	Total w/in Study Area	
Birkhead Mountain Wilderness	0	5,052	5,052	USDA - Forest Service
Black Ankle Bog Preserve	0	286	286	The Nature Conservancy
Densons/ Hugh creeks	0	352	352	Troy (Local)
Fayetteville Public Works Land	598	56	908	City of Fayetteville
FWC Permanent Easement	0	48	48	US Fish & Wildlife Service
Goodwin State Forest	0	1,144	1,144	Div. of Parks & Recreation
Hinson Gameland	0	274	274	Wildife Resources Commission
Hobucken Marsh Preserve	1,724	0	2116	Wildife Resources Commission
Little River Wetland Mitigation Site (Taylor tract)	340	0	340	Sandhills Area Land Trust
McKinney Lake National Fish Hatchery	0	482	482	US Fish & Wildlife Service
Morrow Mountain State Park	0	4,444	4,444	Division of Parks & Recreation
North Carolina Zoological Park	0	184	184	NC Zoological Park
Pee Dee National Wildlife Refuge	0	8,576	8,576	US Fish & Wildlife Service
Pope Air Force Base	1,650	0	1,650	US Dept of Defense
Sandhills Game Land	17,502	39,112	57,898	Wildife Resources Commission
Smith/Burns Tract	44	0	44	Sandhills Area Land Trust
Uwharrie National Forest	0	44,984	44,984	USDA - Forest Service
Weymouth Woods Sandhills Nature Preserve	878	0	878	Division of Parks & Recreation
Whit and Cathy Smith Easement	0	294	294	Land Trust for Central North Carolina
Womble Tract	0	68	68	Sandhills Area Land Trust

Although Fort Bragg has many opportunities to deal with general environmental and sustainable installation issues, they are dealing with a very complicated situation regarding the red-cockaded woodpecker, both on and off the installation (notably in the area between Fort Bragg and Camp Mackall). More importantly, how does this relate to TES issues? The University of Florida researchers already had a good deal of experience dealing with the black bear, so they used this species as the TES for this analysis.[60] The result of this study for Fort Bragg is presented in Table 4-3. In brief, the table suggests

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[60] RCW would have been a better choice for Fort Bragg, but fewer data for North Carolina on the RCW were available during the project.

that Fort Bragg and Camp Mackall contain a large amount of remaining bear habitat—129,820 acres (525.4 km^2; nearly the entire installation of 149,139 acres [603.5 km^2]). Of these acres, most are of medium rather than high priority for the purpose of good habitat usage, but this amount represents about 8 percent of the bear habitat within the larger study area.

Table 4-3. Prioritization areas acreage within Fort Bragg/Camp Mackall study area zones.

Fort Bragg Acreage	141,563
Camp Mackall	7,576
Total Study Area Acreage	2,161,978
% of Study Area Identified in SEF	47.20

Prioritization Layer	Acreage			
	In Study Area	In Installation	Within 5 km	Outside 5 km
Black Bear Priority Habitat				
Medium Priority Habitat	1,456,340	82,398	142,766	1,231,176
High Priority Habitat	50,130	47,422	2,708	0
Interior Forest Priority Areas				
Medium Priority Area	300,166	6,632	13,732	279,802
High Priority Area	0	0	0	0
Priority Wetland Areas				
Medium Priority Area	17,768	164	6,512	11,092
High Priority Area	0	0	0	0

Although the SEF is useful in identifying remaining natural areas of significance in a region, it is somewhat difficult to relate these to military needs for TES management and conservation.

The Corridor Tool

Description

The DoE's Oak Ridge National Laboratory (ORNL) has developed a Corridor Tool that uses landscape-scale, species-specific inputs to identify key spatially explicit characteristics of landscape and habitat fragmentation. This analytical tool can predict the location of corridors of movement between patches of habitat within any map. The algorithm works by launching virtual entities called "walkers" from each patch of habitat in the map, simulating their travel as they journey through landcover types in the intervening matrix, and finally arrive at a different habitat "island." Each walker is imbued with a set of user-specified habitat preferences that make its walking behavior resemble a particular animal species. Because the tool operates in parallel on a supercomputer, large numbers of walkers can be efficiently simulated.

The Corridor Tool uses the concepts of "source" and "sink." For each habitat patch, a relative measure of how easy it is to disperse from there to somewhere else is the definition of how much this patch has the character of a source. How easy it is to disperse to the patch from somewhere else is the definition of how much this patch has the character of a sink. These relative measures are similar to those used by Pulliam (1988), but they are independent of within-patch reproduction. Source and sink importance are calculated for each patch. Manipulation of a series of contrived artificial landscapes demonstrates that the location of dispersal corridors, and relative source and sink importance among patches, can be purposefully altered in expected ways. Finally, dispersal corridors are predicted among remnant habitats within three actual landscape maps. Specifically, the tool can identify critical "connectance points" in a landscape that can therefore be used to direct military resources toward the most critical areas of concern, or otherwise evaluate alternative locations for the degree of suitability to act as potential, long-term habitat recovery sectors.

The Corridor Tool has been tested on theoretical and small realistic areas. The next test was to apply it to a specific region and to a specific species. The specific TES to be modeled is the red-cockaded woodpecker. Using a sample data set, it was possible to model the fragmentation character over the study area. It also was possible to quantify and monitor the location and quality of habitat corridors over a multi-decade time period (1970s-1990s). This particular application uses the 1980s land use database. The Corridor Tool study supports efforts to ensure the interaction of currently isolated populations to protect their long-term viability and genetic diversity.

Protection of long-term viability and genetic diversity is of significance to the Army because the DoD is carrying a large burden of TES management within the study region. To successfully carry out its TES management responsibilities, DoD must cooperate with other Federal, state, and local land managers to provide viable habitats. Otherwise, specific Army installations will become unique TES refuges. This effort the Corridor Tool is meant to objectively and clearly identify areas of greatest significance for RCW habitat preservation using the most advanced research tools available.

Rather than habitat identification, the Corridor Tool is meant to focus on the issues of *fragmentation* and on the identification of critical lands outside of military installations that might not be habitat, but that are critical to the issues of species genetic interaction. The methodology of this particular application was focused specifically on meeting the requirements of the Corridor Tool. It is specifically not intended to develop another RCW habitat model, potential habitat map, or a population dynamic simulation model.

Step-By-Step Procedure to Derive Corridor Tool Inputs

In this example, as is often the case, the military installation possesses detailed habitat data. Although the data on the installation was very detailed for RCW locations and characteristics as well as soils and vegetation distribution, data for the region around the installation was much less detailed. In fact, the only data set that covered the region was the NLCD. It was necessary to extrapolate habitat characteristics from the known area (the installation) to the less-known area in the region around the installation as represented by the NLCD.

Step 1. Geographically locate RCW nesting sites and buffer zones. Identify each known RCW nesting site on the installation as the central point within a 60-m cell. Each cell is surrounded by other 60-m cells in each direction as a buffer zone, giving a 90-m radius around each nest site.

Step 2. Cut out land uses that are within each RCW buffer. Figure 4-4 shows the 90-m buffers around each RCW nesting tree.

Step 3. Identify the land use/land cover that exists within each buffer. Calculate the percentage of RCW nesting area that exists within each land use type. Figure 4-5 shows the land uses existing on the example installation, along with the RCW-site cutouts.

Step 4. Prepare a comparison of RCW nesting areas with the land use categories available on the installation. Column 1 of Table 4-4 lists the land use categories existing on the installation, and Column 2 shows the percent area of each category within the installation. Column 3 shows the percentage of total RCW nesting area that occurs in each of the land use areas.

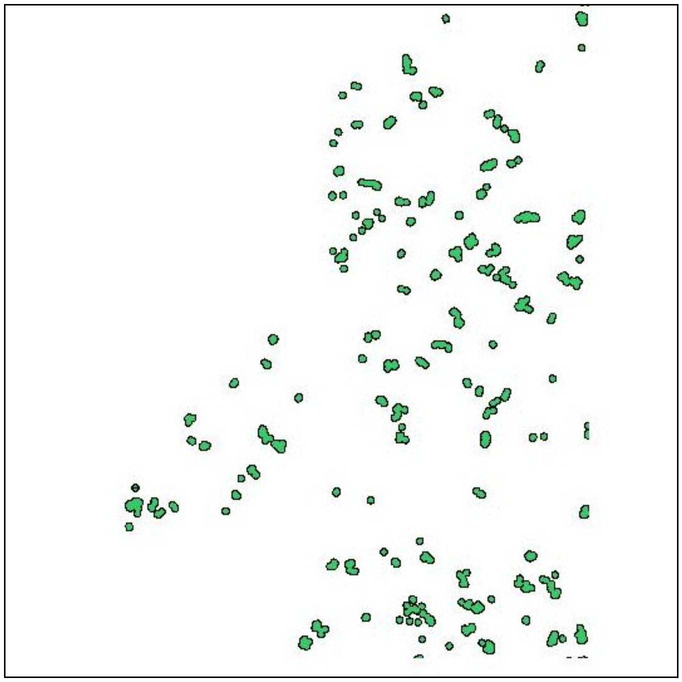

Figure 4-4. RCW buffers within the installation.

Figure 4-5. Land uses within the installation.

Table 4-4. RCW and land use correlations.

Land Use Category*	Pct_of_ installation	pct_of_ RCW_Area	RCW_Dif_from__ installation%
Evergreen Forest	19.8452	30.1836	10.3384
Mixed Forest	30.7228	38.1491	7.4263
Pasture/Hay	0.3081	0.3648	0.0567
Bare Rock/Sand/Clay	0.0015	0	-0.0015
Emergent Herbaceous Wetlands	0.2988	0.1703	-0.1285
Row Crops	1.2636	0.9242	-0.3394
Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, Emergent Herbaceous Wetlands	1.5995	0.7661	-0.8334
Pasture, Hay, Orchards, Vineyards, Row Crops, Small Grains, Fallow, Urban-Recreational	1.5232	0.4256	-1.0976
Shrubland, Grasslands, Herbaceous Upland	1.3667	0.2432	-1.1235
Transitional	2.6024	1.058	-1.5444
Woody Wetlands	6.2234	1.7147	-4.5087
Deciduous Forest	30.1189	24.4436	-5.6753
Quarries/Strip Mines/Gravel Pits	0.0685	0	-0.0685
Commercial/Industrial/Transportation	0.6391	0.4378	-0.2013
Urban/Recreational Grasses	0.7046	0.2311	-0.4735
High Intensity Residential	0.6494	0.1824	-0.467
Low Intensity Residential	1.1364	0.3527	-0.7837
Open Water	0.9281	0.3527	-0.5754

Step 5. Based on this geographic analysis, calculate RCW habitat preferences. The assumption is that in a random RCW distribution, the numbers in the second and third columns would be identical, with RCW area distributed proportionally to the total installation areas within each land use category. The difference between the percentages in the second and third columns indicates a tendency toward active preference (if a positive difference) or low preference/avoidance (negative difference) on the part of the RCW. The difference is shown in the fourth column. This column shows high positive numbers in the Evergreen Forest and Mixed Forest categories, corresponding well with

descriptions in the literature (Hooper 1980 and Lennartz and Henry 1985[61]). It also shows a large negative value for Deciduous Forest, indicating a pattern of markedly lower RCW preference or active avoidance.

Step 6. Proceed to calculate the relative degree of habitat preference, as shown in Table 4-5. The first column of Table 4-5 is carried over from the last column of Table 4-4. In the second column of Table 4-5, similar values are lumped together into six land use (LU) values. The third column shows the average value of each ranked LU value group. The end result, displayed in the fourth column, shows the relative RCW habitat preferences resulting from normalization of the third column. These values are used as the basis for Corridor Tool input matrices, shown in the Chapter 4 Attachment (page96).

Table 4-5. Land use ranking categories.

RCW_Dif_from __installation%	Ranking LU Value	Average LU Ranking	Relative Degree of Habitat Preference	Category
10.3384	1	10.34	1.00	42
7.4263	2	7.43	0.81	43
0.0567	3	-0.63	0.29	81
-0.0015	3	-0.63	0.29	31
-0.1285	3	-0.63	0.29	92
-0.3394	3	-0.63	0.29	82
-0.8334	3	-0.63	0.29	40
-1.0976	3	-0.63	0.29	80
-1.1235	3	-0.63	0.29	50
-1.5444	3	-0.63	0.29	33
-4.5087	4	-5.09	0.00	91
-5.6753	4	-5.09	0.00	41
-0.0685	5	-0.40	0.30	32
-0.2013	5	-0.40	0.30	23
-0.4735	5	-0.40	0.30	85
-0.467	5	-0.40	0.30	22
-0.7837	5	-0.40	0.30	21
-0.5754	6	-0.86	0.27	11

61 From the NatureServe Internet reference materials: http://www.natureserve.org/ Hooper, R.G., A.F. Robinson, and J.A. Jackson. 1980. The red-cockaded woodpecker: notes on life history and management. U.S. Forest Service, Southeast-ern Area, State and Private Forestry, Gen. Rep. SA-GR 9. 8 pp. Lennartz, M. R., and V. G. Henry. 1985. Red-cockaded woodpecker recovery plan (revision). U.S. Fish and Wildife Service. 92 pp.

Step 7. Extend these TES habitat preferences to the regional level of analysis, as a basis for identifying potential habitat areas and migration corridors within the region surrounding the installation. Figure 4-6 shows relative degree of RCW habitat preference extended to the region surrounding the installation. Lighter red indicates more suitable habitat.

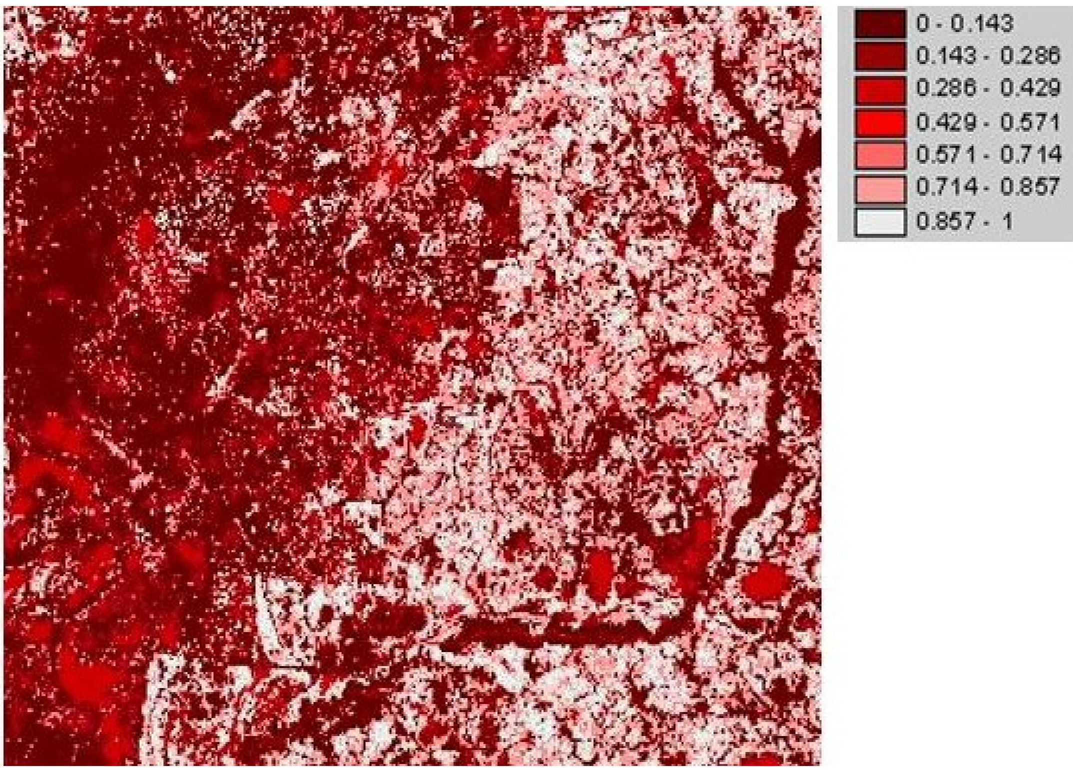

Figure 4-6. Region-wide weighted relative habitat preferences.

Step 8. Further refine the definition of viable habitat and migration corridors by taking into consideration the size of each land use area. Based on Conner and Rudolph,[62] for our example, only patches that are 200 cells/72 hectares or larger are considered viable as sustainable RCW habitat. All such patches were found and extracted from the database.

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[62] Connor, R.N., and D.C. Rudolph. 1991. "Forest habitat loss, fragmentation, and red-cockaded woodpecker population." *Wilson Bull*. 103 (3): 446-457.

Step 9. To proceed with migration corridor analysis, it is necessary to know how far a migrating individual will disperse away from its native colony. For the RCW, the dispersal range is relatively small, around 4 km (Walters et al. 1988).[63] Thus, habitat patches that are 4 km or closer in distance from each other can serve as an RCW migration corridor, while a distance greater than 4 km would be a migration barrier. Figure 4-7 shows large-sized, preferred habitat patches surrounded by 4-km buffer zones. The RCW could migrate within the overlapping zones, but attempts to migrate outside of them become increasingly unsuccessful.

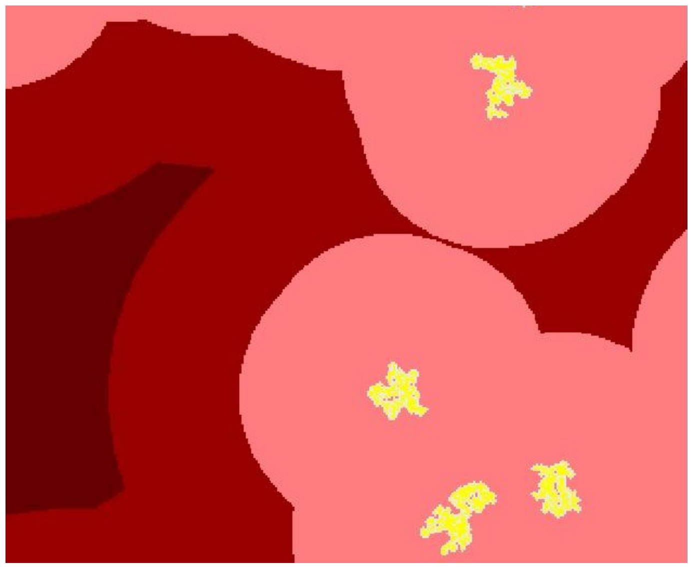

Figure 4-7. 4-km buffers around large preferred RCW habitats (yellow).

Step 10. Use the ArcView Extension Grid Patch to combine RCW 1980s LU preferences (six categories) with Migration Buffers (four categories) from Potential Best Habitat Patches. This combination yields RCW LU Preferences Combined with Migration Buffers, with 24 categories, as shown in Figure 4-8.

63 Walters, J.R., et al. 1988. "Long-Distance Dispersal Of An Adult Red-Cockaded Woodpecker." *Wilson Bull*. 100(3):494-496.

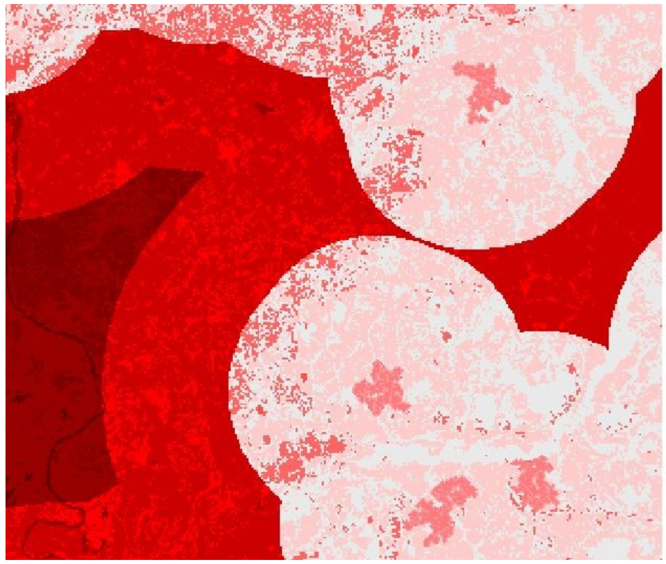

Figure 4-8. Land Use Habitat map: RCW LU preferences combined with migration buffers, 24 categories, no weighting.

Step 11. As part of the Corridor Tool, it is necessary to develop a matrix relating the 24 categories to characteristics of the animal being studied (here RCW) for several major concerns:

- Relative Degree of Habitat Preference: Based on the land use habitat map categories (i.e., those used in Figure 4-8). The landuse habitat map categories reflect the preferences of the RCW and are based on the Relative Degree of Habitat Preference column from Table 4-5.
- RCW Energy Cost to Transit Foraging: The energy expended by the RCW to traverse a cell of each type of habitat. This is a cost of travel.
- Mortality for Transit: The likelihood of mortality (other than starvation) in each type of habitat.

The Chapter 4 Attachment (page 96) includes the completed weights and reasoning. The matrix was developed by first assigning the Relative Degree of Habitat Preference column from Table 4-5 to the same column in the matrix where the land use habitat category was the least distance (i.e., first) buffer. These values are based directly on the calculated data as presented in the Relative Degree of Habitat Preference column in Table 4-5. As the distance increased, the preference value and hence the weights would decrease, depending on the concern at hand and for the reason indicated in the matrix. The values for the RCW Energy Cost to Transit Foraging column Chapter 4 Attachment (page 96) are determined based on the Relative Degree of Habitat Preference column. In most cases, Mortality For Transit is almost vanishingly low for a 60-m cell. To test the Corridor Tool, values were assigned to this column. The intent was to do sensitivity testing with the additional computer runs to see how much difference the different Mortality for Transit values really make.

Step 12. The values shown in Figure 4-8 are weighted by the values in the Chapter 4 Attachment (page 96) matrix from the column entitled Relative Degree of Habitat Preference. The resulting map is then smoothed as shown in Figure 4-9. Notice that the existing tree colonies (yellow) fit well into the more desirable habitat areas shown in light red. Also note that the distance buffers have decreased the quality in areas away from large patches, but have made little difference in areas near large patches.

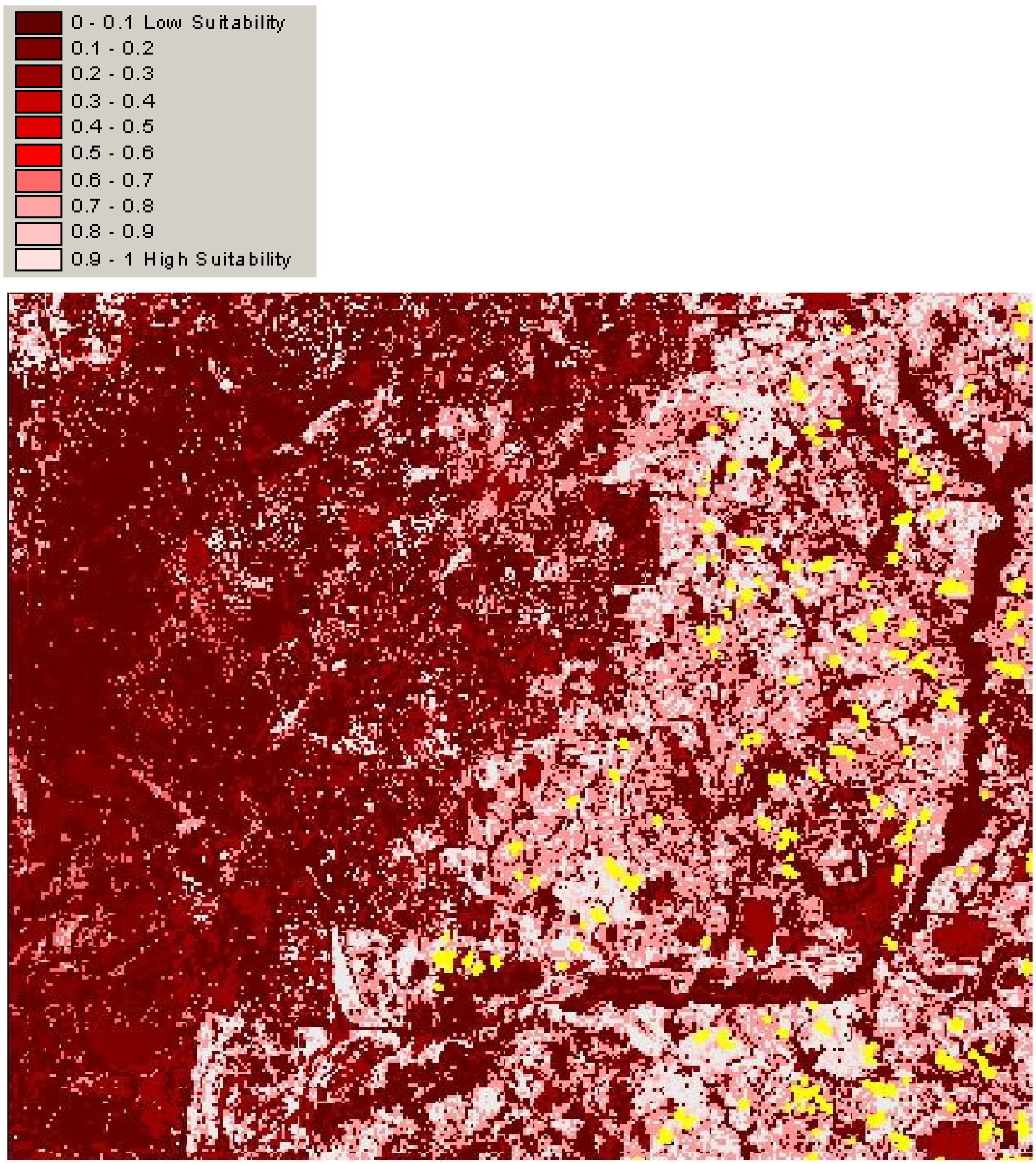

Figure 4-9. Land use habitat map weighted by values in the matrix in the Chapter 4 Attachment, column entitled, Relative Degree of Habitat Preference.

Lighter red indicates better RCW suitability. Existing tree colonies are shown in yellow.

Step 13. There are no limitations on the Corridor Tool other than the amount of memory in the processing computer. It is easy to recode the patches so that those smaller than the minimum area are unacceptable. By doing this, the model will better reflect the real problem, which consists of finding the connections between the patches. Since the land cover maps are derived from remote sensing, they exhibit many "speckles." One- and two-cell patches of habitat can cause the Corridor Tool processing time to skyrocket, since corridors would have to be simulated among all of these very small patches. To avoid this, a minimum usable area was set for the patches, in this case 9 cells, which, if distributed as a square, would be a patch 180 meters on an edge, or 3.24 hectares. This value was chosen because it is below any critical patch size found in the literature. This means that, at 3.24 hectares, all critical information is preserved while eliminating small areas below a threshold in the data. All patches smaller than this minimum were reclassified to another category, and then corridors were sought only among these larger-sized patches. ERDAS Imagine was used to smooth the image (Figure 4-10).

Figure 4-10. Smoothed Land Use Habitat map.
See Figure 4-9; the same patterns exist, but with much less clutter.

Step 14. The final step in development of the land usehabitat map requires distinguishing between home patches that are adequate in size for a viable population (here 200 cells) and those that are not. To determine the home range, the grid patch Category 7 layer was analyzed. All patches of Category 7 greater than or equal to 200 cells were identified and saved as a separated layer. The cell values were changed from the old patch number to create Category 25. The two grids were merged so that the new Category 25 was integrated into the land use habitat map (Figure 4-11).

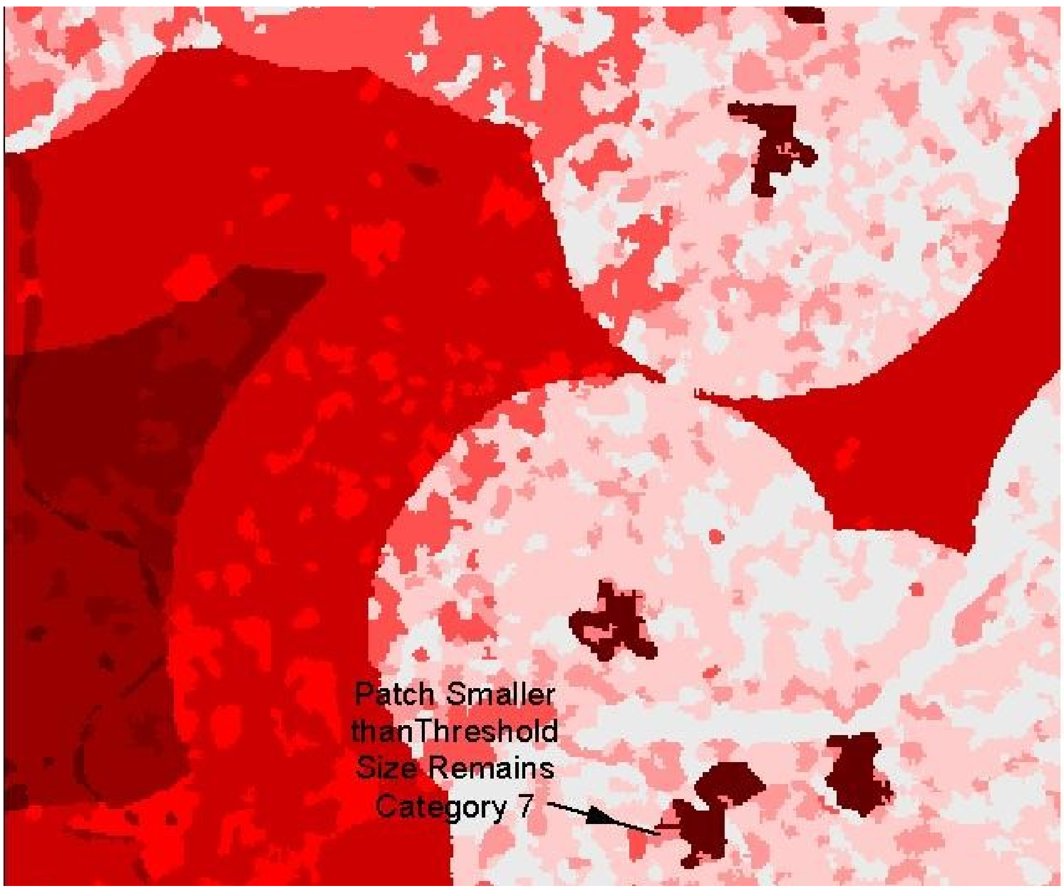

Figure 4-11. Land use habitat map with 25 categories.

Step 15. For input to the Corridor Tool, patch layers were generated. For each of the land uses in the previous step, a spatially explicit patch layer was generated. These layers contain patches (see Figure 4-12) that are consecutively numbered.

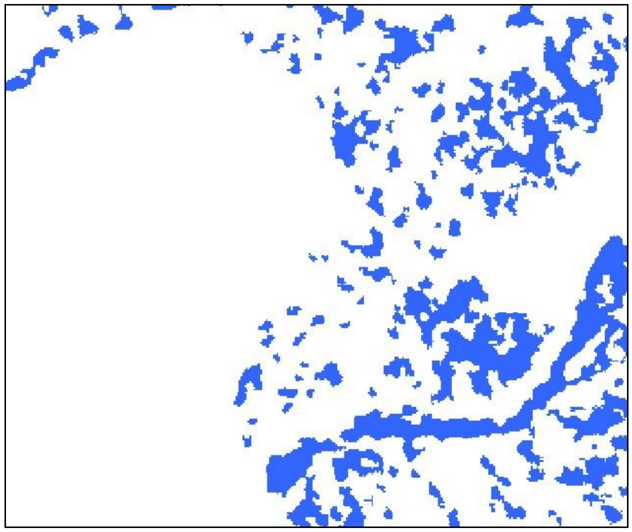

Figure 4-12. Layer containing only Category 1 patches.

Results of the Corridor Tool Approach

Rules of the tool

Habitat fragmentation is just the inverse of habitat connectivity. For TES, the goal is to improve connectivity and strengthen corridors; for invasive species, the goal might be to disrupt connectivity and sever corridors. It has been suggested that a related application is to project the route or spread character of future invasions.

In the Corridor Detection approach, corridors are found among patches of a selected habitat category; habitat patches are the landscape unit of consideration and all patches are treated equally. The Tool uses "virtual" walkers to simulate movements of terrestrial animals, after Gustafson and Gardner (1996).[64] Walkers can be thought of as software agents. They are imbued with the habitat preferences of the target species so that at each step, the walker selects its direction of movement based on habitat preferences supplied for each category by the user. Single walkers that successfully reach another habitat patch (Figure 4-13) are counted in the final outcome. Walkers that run out of energy or die along the way are discarded.

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64 Gustafson, E.J., and Gardner, R.H. (1996) "The effect of landscape heterogeneity on the prob-ability of patch colonization" *Ecology* 14: 94-107.

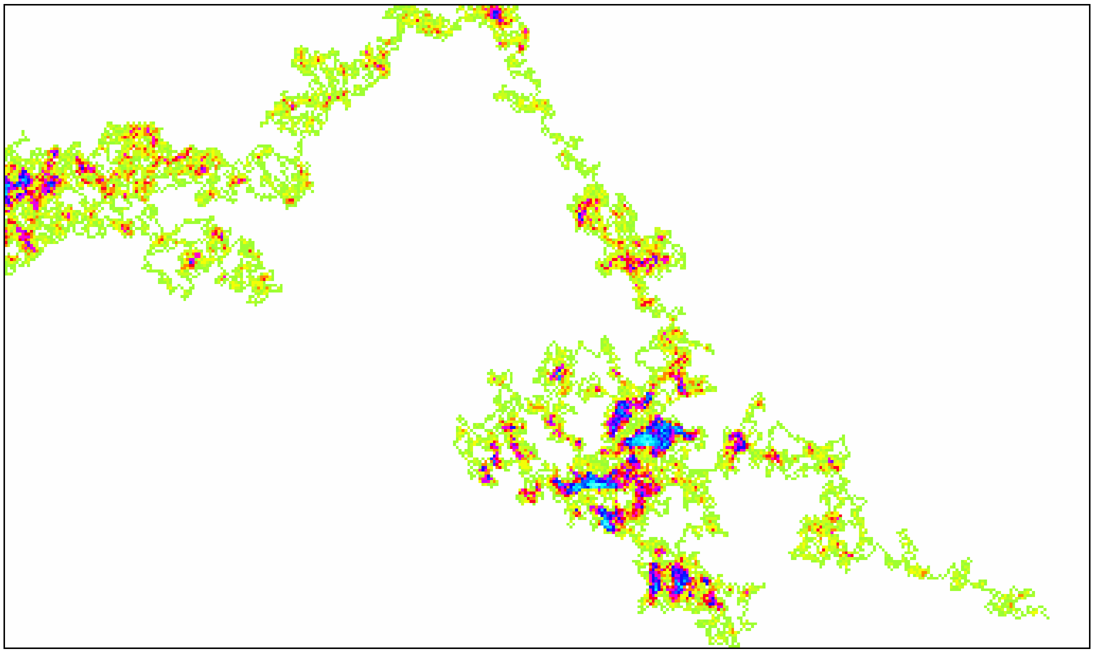

Figure 4-13. Example path of a single successful walker.

The “footprints” of all successfully dispersing walkers are summed together to locate corridors on the map. One can think of the corridors as if they were well-worn footpaths. This assessment simulated large numbers of individual walkers in a Monte Carlo process using a parallel supercomputer to find optimized potential corridors. A constant number of successful dispersers (a “success quota”) is obtained from each patch of origin. All habitat patches have an equal chance to contribute to corridors. Each walker is started at a random location within the patch of origin and each walker starts with a fixed amount of energy that is based on the size of the map. An incorporated “hotfoot” routine encourages walkers to leave their patch of origin quickly and never return. In addition, an “anti-vibrate” routine was applied to discourage backtracking and give walkers realistic directional momentum. Walkers that return to their patch of origin die, and are not counted in corridors. Walkers that enter another different patch of habitat have successfully dispersed.

The Corridor Tool is a mix between an individual-based model and a percolation analysis. Like a percolation analysis, corridor analysis is timeless or instantaneous. An ultimate potential connectivity is the result. Potential connectivity may not be realized as connectivity because there may not be any animals present in some habitat patches, or even in the whole landscape.

Several assumptions have been made to generate potential corridors:

- High-quality habitat is more desirable than less-preferred habitat.

- Short, direct connectors are better than longer dispersal routes.
- Animals will follow an optimum route that minimizes their exposure to low-quality habitat.
- Movement would be facilitated by such routes, whether animals use them or not.
- Resolution of the habitat map may affect the delineation of potential corridors.
- Maps must be large enough to minimize edge effects, but fine enough to reflect the scale at which the animals are making movement choices.

Although, in most cases, these assumptions seem reasonable, one will need to determine whether the assumptions reflect a reality for each species to which the assumptions are applied.

Three types of output products are produced:

1. A map of the most heavily traveled movement pathways between patches of each analyzed map category.
2. A square transfer matrix quantifying "flow" of animals successfully dispersing from each habitat patch to every other habitat patch of that type in the landscape. The transfer matrix is square, since the rate of animal movement is likely to be asymmetrical between any two habitat patches.
3. A set of importance values for every patch in the map that quantifies the contribution of that patch to successful animal movement across the map. This product helps to prioritize remediation, restoration, and management triage actions.

Exchange of individuals among patches is used to calculate a quantitative importance value for each patch. Patch importance is given in the form of both a dispersal matrix and a color-coded patch map.

To carry out the large number of required calculations, it is necessary to parallelize the master/slave algorithm by habitat patch. The master node assigns each habitat patch in the map to a particular node, and then the node keeps sending walkers from the assigned habitat patch until the "success quota" of successfully dispersing walkers is reached. There is a potential problem at this step as a node may be assigned a patch that is surrounded by a barrier, or is completely cut off and disconnected from the other patches. To prevent that node from endlessly sending walkers, it aborts that patch after sending a certain number of walkers without attaining the success quota. A patch that has reached the "abort quota" has less than a specified connectance. The abort quota is like the detection limit for an analytical device, except that it is under the user's control.

Before they are summed, footprints of successfully dispersing walkers are weighted inversely by the square of the energy expended during their traversals. Thus, the most efficient traversal paths contribute more strongly to defining the most-probable corridors. Corridors leading from each patch can be examined individually, if desired. The corridor intensity from each patch is normalized before summing corridors from all patches together, so that all habitat patches contribute equally to the final map of landscape corridors.

Source (origin of migrating individuals) and sink (destination) importance are independent of each other, i.e., they are intransitive. It is assumed that within-patch reproduction is equal across all patches regardless of habitat quality because in this study, there is no evaluation of individual patch quality. It is feasible to assign a relative rating to each patch, but the Corridor Tool does not currently deal with this issue. Source importance is calculated as the ratio of successful dispersers originating in the patch to the total number of walkers (whether successful or not) sent from the patch. Successful walkers originating from aborted patches are counted toward source importance even though the success quota for that patch may not have been met.

In the Corridor Tool, sink importance for a patch is calculated as the ratio of successful dispersers ending up in the patch (having started from some other patch) to the number of all successful dispersers originating from all habitat patches. Successful dispersers from aborted patches make no contribution to sink importance.

Evaluation of initial results

Sources (Figure 4-14) are roughly evenly distributed throughout the study region; a result of the selection of the patches based on NLCD type and minimum size. All centrally located habitat patches are roughly equal in importance as sources of successful dispersers. Habitat patches on the periphery of the map are less important as sources, but this still depends on configuration of the intervening matrix.

The importance of habitat patches as receptors or sinks of successful dispersers exhibits a similar spatial pattern. The rating for sinks is determined by a combination patch size and longest dimension. It actually depends on configuration of the intervening matrix. At the regional scale of the study area, it turns out that the greater number of patches are important as sinks. In fact, the closest unimportant sinks are to the west and north of the installation. If a land manager were looking for off-installation lands to acquire for RCW, these two sinks of low importance are clearly parcels of land to be avoided. Rather there exists a large sink patch at the installation’s southeast corner. This map suggests that the options for TES land acquisition are better focused on that area.

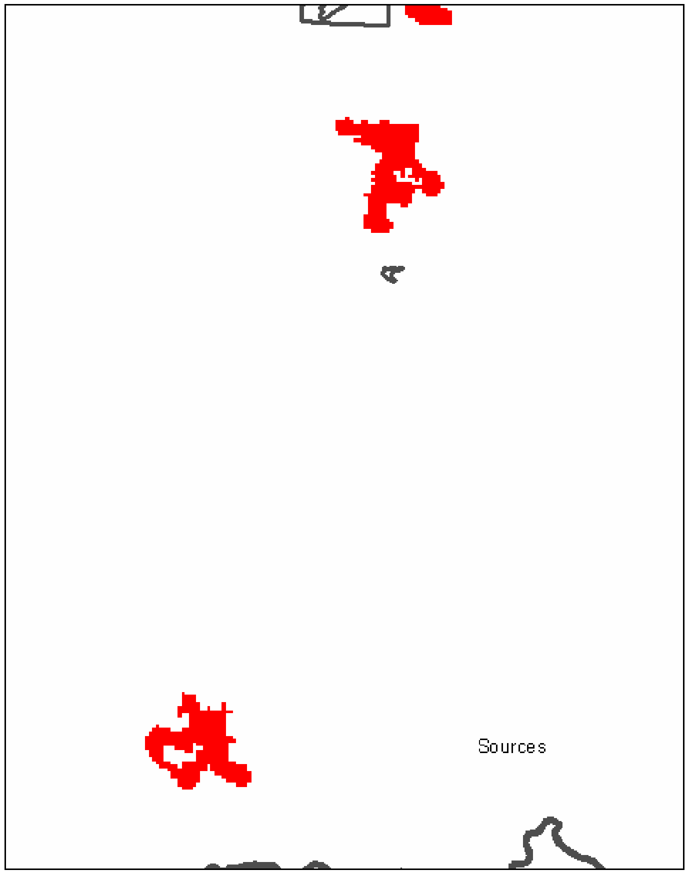

Figure 4-14. Source patch importance.
Redder has more importance as a source.

Figure 4-15 shows the source-to-sink ratio. This map indicates whether populations in habitat patches are likely to be growing or shrinking due to patch placement and matrix configuration alone, irrespective of within-patch reproduction.

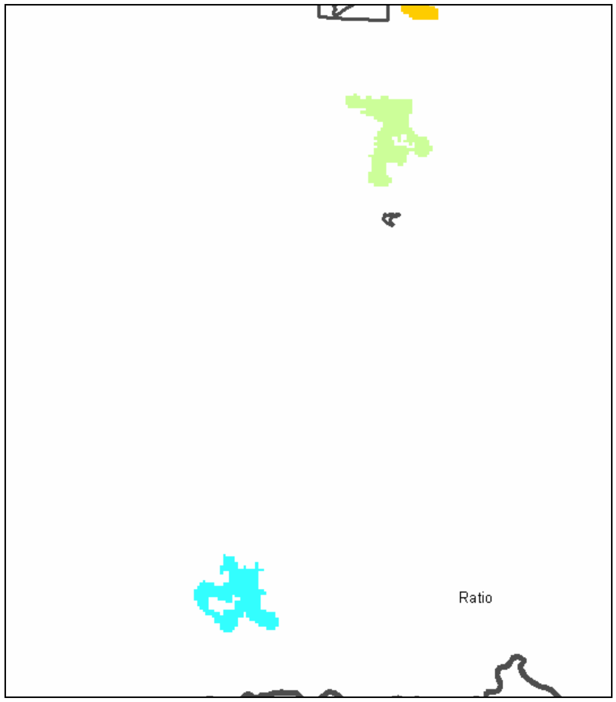

Figure 4-15. Source-to-sink ratio indicates whether populations in habitat patches are likely to be growing or shrinking due to patch placement and matrix configuration alone, irrespective of within-patch reproduction.

On a scale from blue to red, the bluer a patch is, the greater its importance as a source. Conversely, the redder the patch is, the greater its importance as a sink.

Figure 4-16 shows an area-weighted sink importance of RCW patches. This has been normalized by the size of the patch such that, other concerns being equal, larger patches are decreased in importance since their per-unit-area importance value is diluted out over a larger area. This means that conservation and mitigation efforts are best spent on particular small patches that are vitally located. Redder shades (e.g., those near the upper part of the figure) in this image show higher importance.

Figure 4-16. Area-weighted sink importance of RCW patches.
Redder shows higher importance.

Figure 4-17 shows that there is a strong linkage between the lower and middle source patches. However, there also exists a very critical linkage between the top two patches (the top patch is barely visible in the figure). A U.S. highway divides this critical linkage. This map clearly indicates the importance of the middle patch for RCW, as well as the potential hazard from the highway in precluding that linkage.

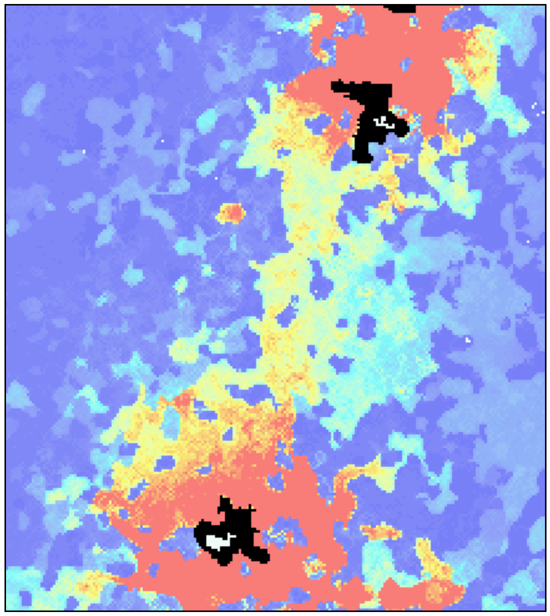

Figure 4-17. Greater number of footprints of successfully dispersing walkers is shown by increasingly hotter colors.

Source/sink patches are in black.

Discussion

Land managers can change source/sink strengths by altering the matrix through which dispersers must pass. These changes can have significant influence even without changing the number, area, or spatial arrangement of habitat patches. Source and sink strengths are comparable across maps, since they are unitless ratios. This means that requesting greater numbers of successful walkers produces more precise predictions. Weighted visualizations show distinct corridors, even through realistic landscapes. Corridors through realistic landscapes are difficult to imagine before they are predicted. Dispersal corridors for invasive or weedy species are important so that they can be disrupted while dispersal corridors for threatened or endangered species are important so that they can be enhanced. These considerations should be useful in the design of biotic preserves or parks consisting of several habitat remnants.

Individual walkers are not strictly analogous to individuals of the target species. Individual animals are much more sophisticated than walkers. Here, large numbers of walkers are used as a spatial optimization process. This optimization process is used to predict the optimum pathways that one expects individual animals to use most often. (This expectation is reasonable because animals are so well adapted to their home environment.) An obverse related issue is, “Are the animals apt to be as efficient in dispersing as are the thousands of walkers in the Corridor Tool?”

Walkers that can see only the habitat types immediately adjacent to their current location can still represent animals that vary widely in the extent of their sensory range. Walkers' single-step look-ahead does not affect the optimization of potential corridors found by the algorithm because the same optimum potential corridors would be found even if walkers were given a greater look-ahead ability. Although shortsighted, a few walkers will make rare suboptimal choices and will cut through bottlenecks to discover optimized pathways beyond. Conversely, walkers that enter attractive but dead-end patches will not successfully disperse; potential corridors that result will effectively show this avoidance of dead-end routes, just as though walkers had greater sensory range. Because animals have a memory, they will use optimum routes, once discovered or learned. However individual walkers do not need memory, since optimized routes are found by the collective action of large numbers of (only) successful walkers.

Summary of Results

The results of the application of the Corridor Tool to the RCW data indicate that:

- The inputs can be configured and the application can be successfully run based on known characteristics of a TES species.
- The results appear reasonable in terms of the character of the TES under review.
- The Corridor Tool has the potential to be of significant use to land managers in general and specifically to military land managers dealing with TES concerns, particularly in off-installation areas where little information is available about potential habitat and habitat fragmentation.
- It is recognized that the work presented here is preliminary. The recognized major problem is to develop a more restrictive input for existing habitat.

Comparison of SEF and the Corridor Tool

The output of SEF is a definition of critical remaining natural areas for ecosystem health. The output of the Corridor Tool example is a definition of important connectivity for a single species. It would be interesting to compare the two in order to see how well the general purpose SEF definition services the needs of a particular TES. It is important to keep in mind that the two are not necessarily expected to coordinate, but if they do, the importance of the high-significance land areas is increased due to validation from two separate sources.

This discussion is limited to the Corridor Tool results of Source Patches and the Importance of Corridor map (Figure 4-17), realizing that this ignores many of the other Corridor Tool results discussed above.

In the Fort Benning region, Figure 4-18 shows the SEF-defined areas in green while the Corridor Tool Source Patch locations are in red. From this map one can say:

- Most of Fort Benning is included in the SEF.
- The SEF defines large areas to the south and less extensive areas to the north of the installation as SEF. Basically Fort Benning is part of a large corridor. (This description is true at the grosser scale beyond that presented here.)
- Most of the source patches do fall within the SEF-delineated locations.
- Some source patches are not included in the SEF (those that are the paler shade of red). An inspection of a satellite image of the area to the north and west of Fort Benning that is not SEF shows that the surce patch areas are indeed parts of forests on the fringe of the town of Columbus. Since the RCW preferences were developed based on a 1980s map, one might expect an older source date to generate source patches that since have become less desirable due to urbanization.

The Corridor Tool definition of Source Patches and SEF coordinate somewhat but not in strict detail.

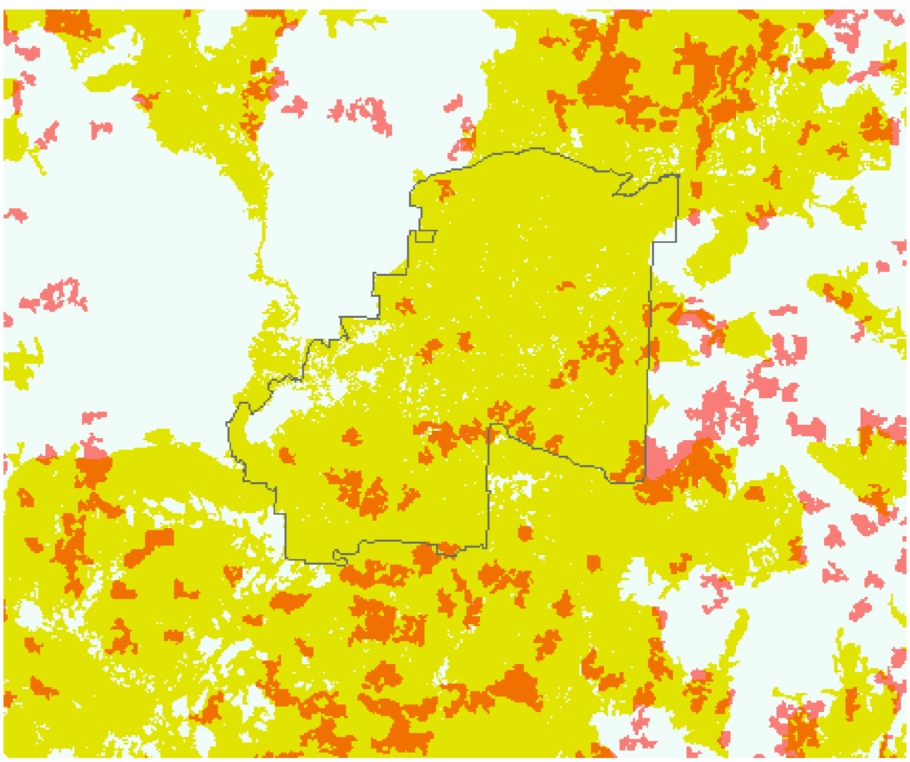

Figure 4-18. SEF (green) compared to Corridor Tool Source Patches (red).

The Importance of Corridor evaluation is intended to show more of the connective nature of the habitat and so is more similar in intent to the SEF. Figure 4-19 presents this correlation. SEF distribution (light green) is overlaid onto the Importance of Corridor map. For the Importance of Corridor map, darker shades of gray indicate increasing importance of TES corridors. Once again although much of the higher importance areas of both maps coincide, this is not necessarily the case; notable exceptions exist. In fact, in Figure 4-19, the same area to the northeast of the installation that does not coincide shows a strong character as corridor. Thus, if source patches exist there, connections will be important. It is significant that none of the connection areas run south into the Columbus urban areas, they are all to the north. Still the area to the north of Columbus is not included in the SEF.

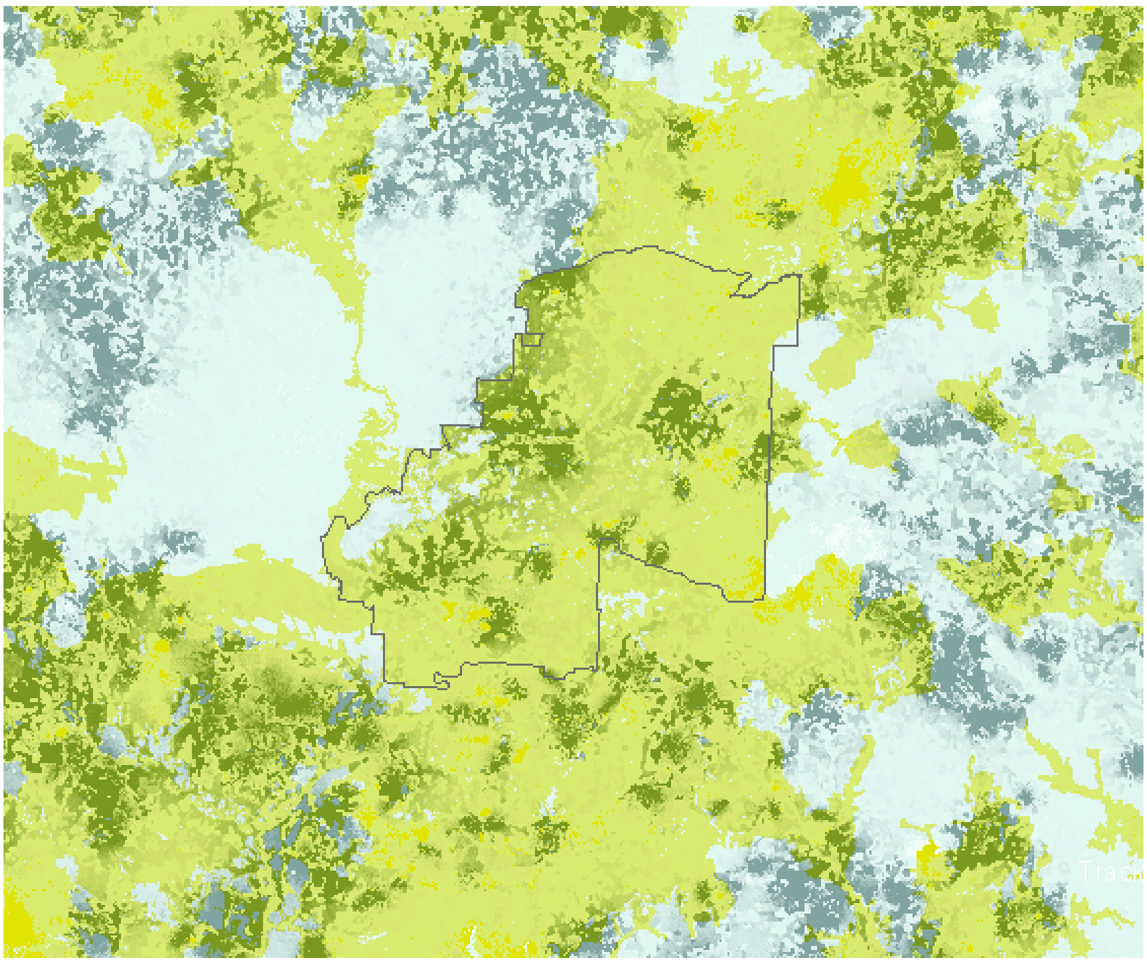

Figure 4-19. SEF distribution (light green) compared with the Importance of Corridor map (shades of gray).

The conclusion from this comparison of the Corridor Tool and SEF is that the two do not coordinate highly with each other. Although the SEF may be a good point of departure, it is not designed to be a TES fragmentation/corridor model, at least in this comparison. Thus, fragmentation studies for a specific TES should be based on that specific TES.

Conclusion

This discussion compared two differing approaches to the issue of identifying TES migration corridors: The Southeast Ecological Framework (SEF) and the Corridor Tool. Each takes a regional approach so that comparisons between geographically widely separated areas are viable. In this aspect they are an improvement over the National Biological Service GAP Analysis initiative that, although federally sponsored, was a state-based program. In addition, all of the techniques recognize the importance of satellite remote sensing imagery as a critical basic data component. That is, their primary data is generated either directly or secondarily from imagery sources. Although one may initially believe that since the intent to define important areas or linkages is similar, that the outcome of these different approaches would result in similar outcomes. The review here does not bear this out.

The SEF as was created through a systematic landscape analysis of ecological significance and the identification of critical landscape linkages. The SEF is a broad approach to defining areas of natural importance and their interconnections. Most military installations in the SEF are considered to be “hub areas”. Although a good point of departure, for the purposes of military land managers, the SEF delineation is not detailed enough to provide specific guidance for land acquisition/land conservation activities beyond the installation boundaries.

The Corridor Tool is a step in the correct direction. It suffers from two major problems. The first is perception. When people are reviewing the tool it seems that it is nearly impossible to keep the discussion aimed on the issue of the connection between habitats rather than the habitat itself. The Corridor Tool begins with the assumption that it is given a correct habitat delineation and works out the characteristics of connectivity for a particular species. Thus it deals with the issues of both habitat and viability and potential to spread out over time of the species. The second problem is the delineation of a habitat. As we have seen from previous chapters, remote sensing, usually satellite imagery, is the only cost-effective means to generate base data at a landscape scale. But, the state of the art does not allow the application of national land use data derived from imagery to adequately limit those areas that are really potential habitat. Once again land managers are faced with the dilemma of having sophisticated modeling capabilities but the models run on data that is inadequate to address the model requirements. On the other hand, the outputs are tailored to provide specific guidance for land acquisition/land conservation activities beyond the installation boundaries.

Chapter 4 Attachment: Corridor Tool Matrix Input Table

Table 4-A-1. Corridor Tool Matrix Input

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
1	2	4	60 m–4 km	Avoid	0	No compatibility — Straight from Relative Degree of Preference	0.15	Birds can transit, but further from more suitable areas so less likely, possibly find a bit	0.94	Birds die and transiting increases that slightly
2	2	3	60 m–4 km	No Matter	0.28	This is normal home range	0.25	Poor area to gather food and far away from good habitat	0.96	Transiting Birds are further away from best habitat
3	2	2	60 m–4 km	High	0.8	Within normal home range	0.75	Nearly Good	0.97	Transiting Birds can be a long way from best habitat
4	2	1	60 m–4 km	Highest	0.99	This is normal home range	0.95	Nearly Best, similar to “At Home” situation	0.98	Transiting Birds are further away from best habitat
5	1	3	Best RCW Habitat Patch	No Matter	0.29	Moderate compatibility—Straight from Relative Degree of Pre	0.3	Poor area to gather food	0.97	Nearly as safe as being at home.
6	1	2	Best RCW Habitat Patch	High	0.81	High compatibility—Straight from Relative Degree of Preference	0.81	Good	0.98	Nearly as safe as being near home.

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
7	1	1	Best RCW Habitat Patch	Highest	1	Straight from Relative Degree of Preference—area Not large enough for viable colony	1	Best, similar to "At Home" situation	0.99	Nearly as safe as being near home.
8	1	4	Best RCW Habitat Patch	Avoid	0	No compatibility—Straight from Relative Degree of Preference	0.2	Birds can transit, possibly find a bit	0.95	Nearly as safe as being at home but now may be a long distance.
9	1	5	Best RCW Habitat Patch	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.3	Poor area to gather food	0.97	Away from normal cover—vulnerable, even though not very likely
10	2	5	60 m–4 km	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.25	Poor area to gather food and far away from good habitat	0.96	Away from normal cover—vulnerable, even though not very likely
11	2	6	60 m–4 km	Water	0.02	Water is not a RCW habitat	0.05	No RCW Food in water areas, more distant from suitable areas so 1/2 previous	0.96	Away from normal cover—vulnerable, even though not very likely
12	1	6	Best RCW Habitat Patch	Water	0.02	Water is not a RCW habitat	0.1	No RCW Food in water areas, however water availabilty is positive, prevents zero rating.	0.97	May be a long way from normal cover

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
13	3	3	4 km–8 km	No Matter	0.23	Slightly beyond home range	0.25	Poor area to gather food and far away from good habitat	0.96	Away from normal cover in a place normally to avoid—vulnerable, even though not very likely
14	3	4	4 km–8 km	Avoid	0	No compatibility—Straight from Relative Degree of Preference	0.15	Birds can transit, but further from more suitable areas so less likely, possibly find a bit	0.94	Away from normal cover in a place normally to avoid—vulnerable, even though not very likely
15	3	2	4 km–8 km	High	0.75	Slightly beyond home range	0.75	Nearly Good	0.97	Away from normal cover in a place normally to avoid—vulnerable, even though not very likely
16	3	5	4 km–8 km	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.25	Poor area to gather food and far away from good habitat	0.96	Can be really far Away from normal cover in a place normally to avoid—vulnerable, even though not very likely
17	3	1	4 km–8 km	Highest	0.95	Slightly beyond home range	0.95	Nearly Best, similar to “At Home” situa-	0.98	Away from normal cover—

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
								tion		vulnerable, even though not very likely
18	3	6	4 km–8 km	Water	0.02	Water is not a RCW habitat	0.025	No RCW Food in water areas, more distant from suitable areas so 1/2 previ-ous	0.96	Away from normal cover—vulnerable, even though not very likely
19	4	2	Greater Than 8 km	High	0.65	Beyond nor-mal range	0.75	Nearly Good	0.96	Away from normal cover—vulnerable, even though not very likely
20	4	4	Greater Than 8 km	Avoid	0	No compati-bility—Straight from Relative De-gree of Pref-erence	0.15	Birds can transit, but further from more suitable areas so less likely, possi-bly find a bit	0.93	May be a long way from normal cover
21	4	3	Greater Than 8 km	No Matter	0.18	Beyond nor-mal range	0.25	Poor area to gather food and far away from good habitat	0.95	Similar to Moderate
22	4	1	Greater Than 8 km	Highest	0.85	Beyond nor-mal range	0.9	Nearly Best, similar to "At Home" situa-tion	0.97	Similar to Moderate
23	4	5	Greater Than 8 km	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.25	Poor area to gather food and far away from good habitat	0.95	Similar to Moderate
24	4	6	Greater Than 8 km	Water	0.02	Water is not a RCW habitat	0.012	No RCW Food in water areas, more distant from suitable areas	0.93	Greater than 8 km may be a long way to fly, increased

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
								so 1/2 previ-ous		danger.
25	1	1	Best RCW Habitat Patch	Highest	1	Straight from Relative De-gree of Pref-erence, area large enough for viable colony	1	Best, similar to "At Home" situation	0.99	Nearly as safe as being near home.

5 Population Viability Analysis

H. Resit Akçakaya, Kelly Cantara, Heather Vaillant, David Diamond, Diane True, William Wolfe, and Robert Lozar

Review of Habitat Fragmentation (Software) Models

Although Army lands must primarily support troop training, the Army is also required to manage its training lands to meet other objectives, e.g., maintaining threatened and endangered species (TES) habitat. A good deal of residential and commercial development is occurring outside the installation boundaries. Because military training has traditionally been carried out in more natural settings, military lands are increasingly becoming more important as TES habitats as development for commercial and residential land uses fragment habitat elsewhere. By itself, the amount of land available on military installations is insufficient to ensure a TES populations' long-term viability. Primary TES habitat must remain genetically connected with off-installation areas.

As development increases, the remaining natural areas are affected in two important ways:

- Urban development reduces the amount of available natural habitat—decreasing the total carrying capacity for certain species and making smaller populations more susceptible to extinction.
- Urban development fragments (disconnects) the remaining habitat. That is, animals and propagules from plants in remaining good habitats cannot reach other populations through migration or dispersion of plant pollens and seeds. The "islands" of remaining habitat lose their genetic connectivity; this phenomenon is called "habitat fragmentation."

Certain animals' behaviors and habitat requirements, and some plants' seed and pollen dispersal approaches may tolerate habitat fragmentation better than others. A given landscape may be fragmented for one organism, but not for another. Patterns of fragmentation can also differ. The loss of genetic connectivity will eventually result in the loss of genetic diversity in subpopulations, making the populations more susceptible to disasters and increasing the probability of local extinction. Habitats must not become so fragmented that small populations become isolated.

This occurrence has resulted in the loss of installations land to training. Thus, habitat fragmentation is a concern to the military.

A number of tools (i.e., "fragmentation models") that quantify the effect of habitat fragmentation on the viability of threatened and endangered species, promise to help address the double challenge of development encroachment near installations while training lands are experiencing increasing usage demands. A study done by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) reviewed a number of habitat fragmentation models to evaluate and identify the relative strengths and weaknesses of landscape scale TES habitat fragmentation models as they relate to military installations within the United States (Akçakaya et al. 2006[65]). The work reviewed 12 habitat fragmentation models. Of those, 6 were run using similar data inputs to further refine the comparison. In a follow-on study, an in-depth investigation was performed on one model at Fort Hood, TX; a summary is presented near the end of this chapter.

The 12 reviewed models were (tested models are noted with an asterisk [*]):

1. FragStats*
2. FragStats ARC
3. R.L.E. (Raster Landscape Ecological) Model
4. Patch Analyst*
5. Habitat Analysis and Modeling System (HAMS)*
6. Habitat Suitability Index (HSI) Model*
7. California Urban and Biodiversity Analysis Model (CURBA)
8. Land Transformation Model (LTM)
9. Land-Use Change Analysis System (LUCAS)
10. RAMAS GIS*
11. Effective Area Model (EAM)*
12. The DIAS RCW (Dynamic Information Architecture System Red-cockaded Woodpecker) Mode.

The following sections describe the tested fragmentation models. This is not to imply that those not included here are inferior for fragmentation evaluation purposes.

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65 Akçakaya, H. Resit, Kelly Cantara, Heather Vaillant, David Diamond, Diane True, Chris C. Rewerts, and Robert Lozar, *Evaluation of Models To Support Habitat Fragmentation Analysis*, Technical Report, 03 Aug 06, ERDC-CERL, Champaign, IL, Report Number ERDC/CERL TR-06-18.

For a more complete discussion, readers are invited to review the above referenced Akçakaya publication.

FragStats

Overview

FragStats is a program designed for the spatial analysis of categorical maps. It quantifies the areal extent and spatial configuration of patches within a landscape that is defined and scaled by the user. Landscape metrics are then used to quantify patches on three levels: individual patches, classes of patches, or entire landscape mosaics. Landscape metrics fall into two categories: those that quantify the map composition without reference to spatial attributes, and those that quantify the spatial configuration of the map. FragStats is a statistical program rather than a fragmentation model. Yet, it set the standards for most existing models and its metrics are often integrated into the fabric of the more recent models. Table 5-1 shows a series of standard FragStats outputs.

Strengths

FragStats analyzes the extent and spatial configuration of patches within a landscape using metrics. These metrics are very well defined and specific. FragStats is therefore an extremely thorough tool for analyzing landscape structure, particularly habitat fragmentation.

Shortcomings

FragStats has four primary shortcomings as a tool for analyzing the effects of habitat fragmentation:

- FragStats analysis is based on predefined patches or habitat categories. To be useful in habitat fragmentation assessment, the definition, and the spatial scale of patches must be determined for a particular species before the analysis. This would require a habitat analysis for the species, and considerations of behavioral characteristics of the species (territoriality, home range, dispersal, etc.) that affect its use of space, which must be determined before an analysis by FragStats is carried out.
- FragStats is designed to analyze the extent and spatial configuration of patches within a landscape, and is not able to analyze the effects of habitat structure on floral or faunal species. That must be done using principal components analysis (PCA), regression, or ArcView GIS methods. All of these methods would require determining the biological variable (such as abundance, survival, fecundity, etc.), and collecting spatially explicit data on this variable. Note too, that analysis of species using these methods will only account for landscape metrics, and does not take into consideration variables such as food availability, microclimate, etc.

Table 5-1. Example of FragStats model output on the landscape scale.

Landscape-level Metrics

Metric	Fort Bragg	Fort Stewart
TA	4390400	9421100
NP	4735	6875
PD*	0.1078	0.073
LPI	22.63	25.46
LSI	40.96	54.20
AREA_MN	909.27	1365.21
AREA_AM	311833.77	835674.48
AREA_MD	100	100
AREA_RA	993300	2398300
AREA_SD	16814.12	33749.15
AREA_CV	1849.19	2472.09
SHAPE_MN	1.2039	1.2578
SHAPE_AM	9.241	13.01
SHAPE_MD	1	1
SHAPE_RA	16.71	23.81
SHAPE_SD	0.6618	0.7808
SHAPE_CV	54.97	62.08
CORE_MN	909.27	1365.21
CORE_AM	311833.77	835674.48
CORE_MD	100	100
CORE_RA	993300	2398300
CORE_SD	16814.12	33749.15
CORE_CV	1849.19	2472.09
DCORE_MN	909.27	1365.21
DCORE_AM	311833.77	835674.48
DCORE_MD	100	100
DCORE_RA	993300	2398300
DCORE_SD	16814.12	33749.15
DCORE_CV	1849.19	2472.09
FRAC_MN	1.0203	1.0243
FRAC_AM	1.1696	1.1907
FRAC_MD	1	1
FRAC_RA	0.2578	0.2798
FRAC_SD	0.0337	0.0368
FRAC_CV	3.3037	3.5901
PARA_MN	34.95	33.99
PARA_AM	16.09	13.94
PARA_MD	40	40
PARA_RA	32.87	34.18
PARA_SD	7.02	7.69
PARA_CV	20.08	22.64

Metric	Fort Bragg	Fort Stewart
CONTIG_MN	0.1133	0.1364
CONTIG_AM	0.5831	0.6377
CONTIG_MD	0	0
CONTIG_RA	0.8144	0.846
CONTIG_SD	0.1538	0.1716
CONTIG_CV	135.74	125.83
PAFRAC	1.5857	1.577
ENN_MN	2758.83	2806.35
ENN_AM	2140.04	2118.74
ENN_MD	2236.07	2236.07
ENN_RA	25513.63	110294.26
ENN_SD	1582.19	2441.20
ENN_CV	57.35	86.99
CONTAG*	27.85	32.77
PLADJ	59.77	65.14
IJI	80.67	77.31
COHESION	96.14	97.65
DIVISION	0.9303	0.9116
MESH	305796.54	832543.28
SPLIT	14.36	11.32
PR	6	6
PRD	0.0001	0.0001
RPR	66.67	66.67
SHDI*	1.4353	1.5211
SHEI*	0.801	0.8489
AI	60.35	65.59

Some Interesting (non-significant) Differences

Metric	Bragg	Georgia	% Difference
PD	0.1078	0.073	32.28%
CONTAG	27.85	32.77	17.66%
SHDI	1.4353	1.5211	5.98%
SHEI	0.801	0.8489	5.98%

PD—patch density (# patches/100ha)
CONTAG—aggregation of patch types (%)
SHDI—Shannon's Diversity Index
SHEI—Shannon's Evenness Index

- It is often difficult to interpret the results of FragStats for the purposes of predicting fragmentation impacts, e.g., to predict the future population responses in the same landscape, or the population responses in another landscape, or the response of another species. The reason is that there are no *general* relationships between landscape indices and the persistence of populations inhabiting the landscape. In specific cases, the relationships vary with species, with landscape, and with the spatial scale.
- FragStats cannot analyze changes in patch or landscape dynamics, such as perforation, dissection, shrinkage, or attrition.

Patch Analyst

Overview

The fact that Patch Analyst is integrated into ArcView GIS (which provides tools for mapping and graphic analysis of data) gives this model an advantage over other landscape structure models, which have to be formatted and input into a GIS for further analysis.

Strengths

Patch Analyst is free and an extension integrated into ArcView GIS (and now ArcGIS), making this an economical initial means of beginning habitat fragmentation analysis. An installation GIS specialist can begin this work without the need to buy expensive software or contract out the analysis.

Shortcomings

Patch Analyst shares the four primary shortcomings of landscape structure models discussed above. In addition, Patch Analyst is very time consuming in performing calculations of metrics. This puts limitations on the number of metrics that can be reasonably calculated for a given study (Apan et al. 2002).[66]

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[66] Apan, Armando A., Steven R. Raine, Mark S. Paterson (2002) Mapping and analysis of changes in the riparian landscape structure of the Lockyer Valley catchment, Queensland, Australia *Landscape and Urban Planning*,59:43-57.

Habitat Analysis and Modeling System (HAMS)

Overview

The HAMS PC-based software program provides graphical, analytical, and modeling capabilities and allows users to graphically display, measure, modify, and analyze landscape structure. The program can evaluate habitat suitability for a species or group of species by providing an estimate of the density of the species within the study area (Figure 5-1). This is done using Pattern Recognition (PATREC) models, specified for the life requirements of the species under study.

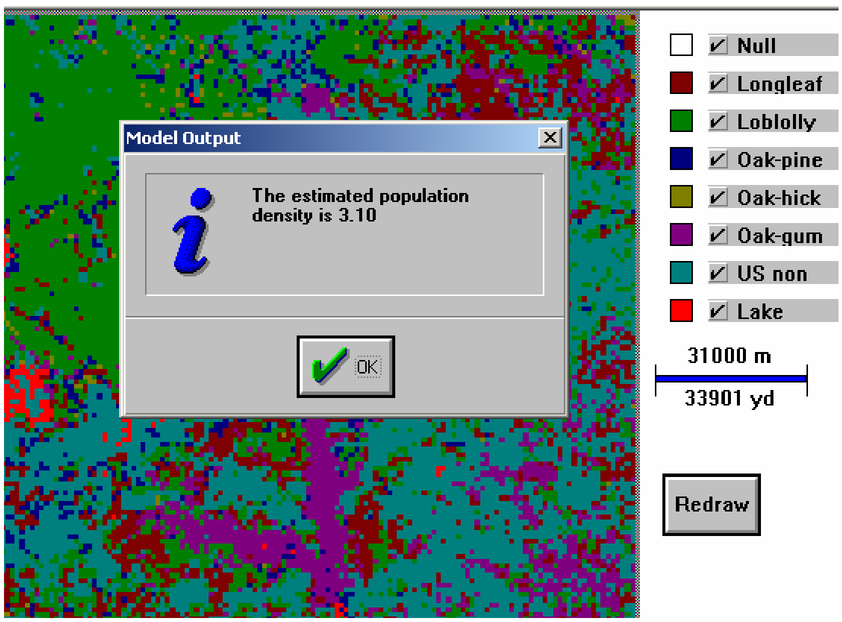

Figure 5-1. Example of a habitat suitability output, in the form of an estimated species density.

Strengths

HAMS' strength is its ability to analyze habitat patches and assess habitat suitability via a species' density estimate, all in one program.

Shortcomings

HAMS is little known, hard to obtain, and has no technical support available. Although the program can analyze the suitability of a habitat by providing an estimate species' density, it only uses landscape metric information as specified by the user, who must have expertise in the life requirements of the species, as it relates to landscape structure. Finally, like the other habitat models, HAMS evaluates landscapes based only on habitat, and cannot assess a species' abundance or persistence (viability) in the landscape. The primary method used in HAMS is PATREC, which is not very widely used or recognized.

As with FragStats and Patch Analyst, HAMS requires further analysis such as PCA, regression, or Spatial Analyst modeling must be done for TES assessment.

Habitat Suitability Index (HSI)

Overview

HSI models are widely used, as they allow wildlife to be represented with other natural resource information by recording or predicting the response of a species to its environment (Kliskey et al. 1999)[67]. Habitat is usually a key factor in determining a species' presence or abundance, but there are also other factors involved, such as food availability. HSI models attempt to quantify habitat quality using factors shown to be important to the species in question, and creating an index of habitat suitability determined by aggregating one or more factors considered life-requisite components; its values range from 0.0-1.0 (Lancia et al. 1982).[68] It should be noted that habitat suitability indicates the habitat quality for the species (Figure 5-2), not its abundance. HSI models are based on the assumptions that a species will select and use areas that are best able to satisfy its life requirements, and that consequently, greater use will occur in higher quality habitat (Schamberger and O'Neil 1986).[69]

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[67] Kliskey, A. D., E. C. Lofroth, W. A. Thompson, S. Brown, and H. Schreier. 1999. Simulating and evaluating alternative resource-use strategies using GIS-based habitat suitability indices. Landscape and Urban Planning 45:163-175.

[68] Lancia, R. A., S. D. Douglas, D. A. Adams, and D. W. Hazel. 1982. V*alidating habitat quality assessment: an example*. Trans. North Amer. Wildl. Nat. Res. Conf. 47:96-110.

[69] Schamberger, M. L., and L. J. O'Neil. 1986. "Concepts and constraints of habitat-model testing." Pages 5-10 in J. Verner, Morrison, M.L., Ralph, C.J., editor. *Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*. University of Wisconsin Press, Madison, WI.

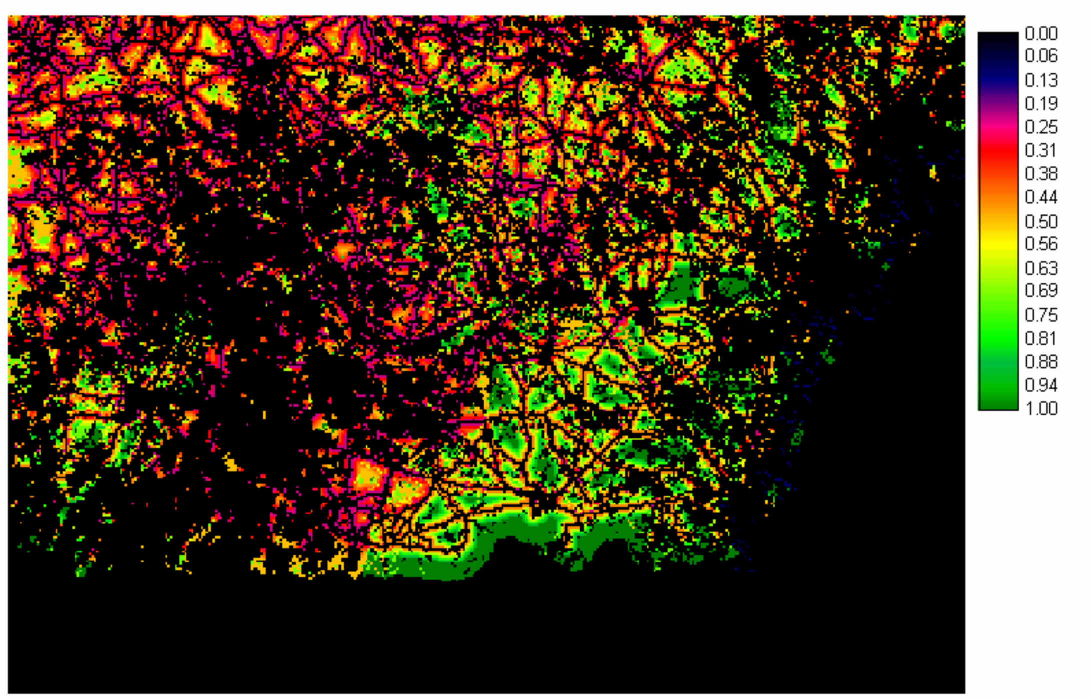

Figure 5-2. Idrisi GIS map of habitat suitability for the red-cockaded woodpecker near Fort Stewart, GA.
Note that this map was developed as a test of the HIS model and as such is not intended to reflect an in-depth evaluation result.

Strengths

The HSI model is very simple and straightforward. A computer is not even necessary to compute the suitability of a habitat patch, although one is required to effectively suitability and variation in suitability over a large landscape area.

Another advantage of HSI models is that they use life requisite variables other than landscape metrics, such as food availability and climate. A species' suitability to a habitat is rarely, if ever, only a function of landscape structure, and these other variables are extremely important in calculation of a viable HSI.

Shortcomings

One shortcoming of the HSI model is that the variables selected for inclusion in the model, and the shape of the function for each variable, are usually based on expert opinion and can therefore be subjective. Different experts, using the same data on the same species, may come up with different models. Another important limitation is that the form of the function is restrictive and arbitrary. It does not readily allow for interactions between variables, and often requires assumptions of linearity between a habitat variable and the species' response to the variable (Van Horne 1983).[70]

Finally, a major shortcoming of HSI models (as well as other, more advanced habitat modeling methods) is that they describe habitat suitability, but do not predict the viability or persistence of the species in that habitat, because viability depends on factors other than habitat suitability, including landscape-level factors (total amount of habitat, expected future change in the amount, spatial distribution of habitat, etc.), and demographic factors (survival, fecundity, and dispersal as functions of habitat; exploitation and other impacts not related to habitat, etc.).

RAMAS GIS

Overview

RAMAS GIS, which consists of five programs (Metapopulation, Spatial Data, Habitat Dynamics, Sensitivity Analysis, and Comparison of Results) is designed to link GIS-generated landscape data to a species' metapopulation model for extinction risk assessment, viability analysis, reserve design, and wildlife management. It works by combining landscape spatial data, habitat requirements of a given species, and demographic data into a metapopulation model. The model is then run to simulate future changes in species abundance and distribution in the landscape, or to estimate the risk of extinction or decline and time to extinction. The model can be run for varying landscape structures, to assess a species' response to development or management actions.

Strengths

RAMAS GIS can model a species' response (in terms of population size or viability) to habitat change, as well as to other human impacts or conservation actions. Other models reviewed can describe the landscape (FragStats, R.L.E., Patch Analyst), describe the suitability of a single habitat to a species (HSI), or describe the changes in landscape over time (CURBA, LUCAS), but none of them can translate a time series of habitats into a species' response.

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[70] Van Horne, B. 1983. "Density as a misleading indicator of habitat quality." *Journal of Wildlife Management* 47:893-901.

RAMAS GIS also has the ability to link to models that predict landscape change. A recently developed addition, RAMAS Landscape, links the program to the landscape model LANDIS (which predicts forest landscape structure in terms of tree species composition and age classes). In principle, the program can be linked to any model that predicts the future landscape in the form of a time series of raster maps.

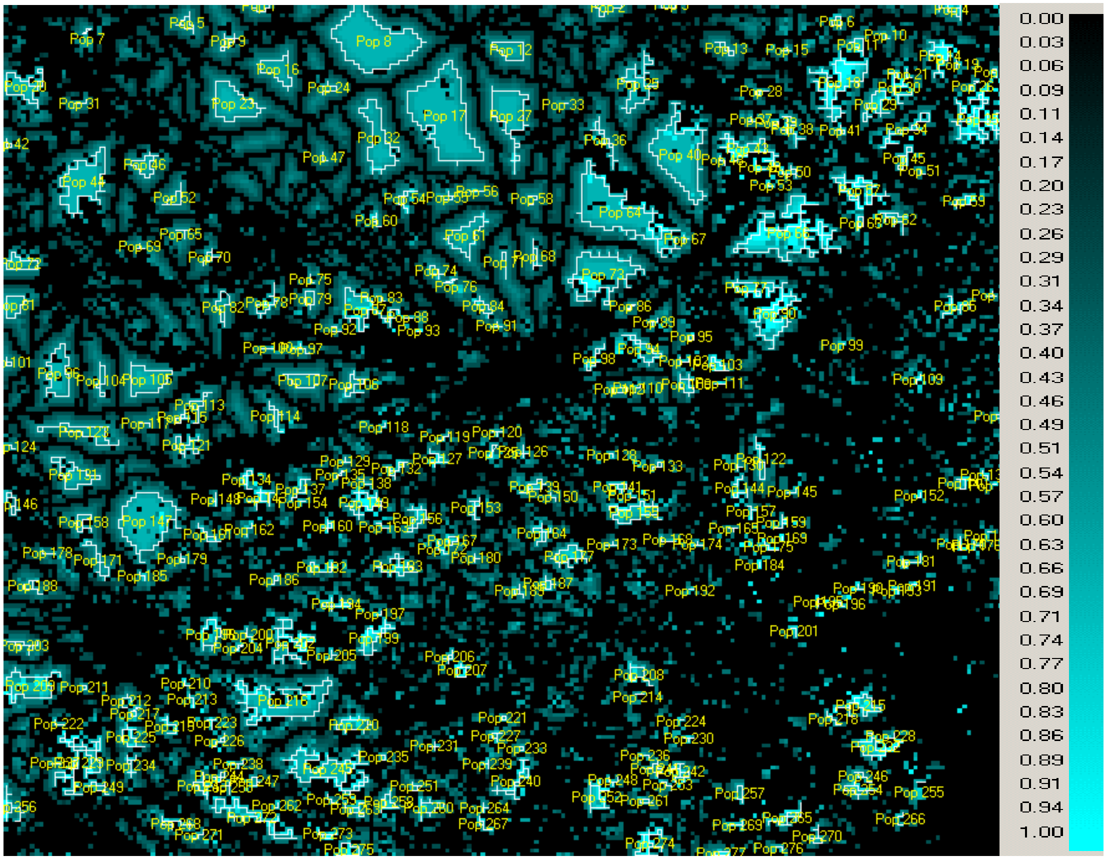

Figure 5-1. Habitat suitability map showing potential population locations for the red-cockaded woodpecker near Fort Bragg, NC.
Populations are indicated by the yellow circle and labeled with “Pop #”.

Shortcomings

RAMAS GIS allows only one-way interaction between the landscape data and the metapopulation model. The program does not estimate the function that relates landscape data to habitat suitability or to the parameters of the metapopulation model. These functions need to be input manually, and must be estimated using logistic regression or some other method.

Input parameters are not estimated in this model; the user must research relevant literature and use that information to estimate input parameters. RAMAS GIS (and in general, habitat-based viability methods) require more information than habitat suitability models, because they require demographic information in addition to habitat information.

Effective Area Model

Overview

The Effective Area Model (EAM) was designed to provide a predictive tool for linking field and remote sensing data in a landscape model to permit comparison of the impacts of alternative management strategies. The EAM is an extension to ArcView GIS, adding a menu called "EAM" to the menu bar of the ArcView graphical user interface. It uses quantitative measures of species-specific edge effects to weight habitat quality within a patch, based on distance from the edge. The model then calculates an "effective habitat area" for each habitat patch within the study landscape or management area. This enables the prediction of changes in species' density and abundance given changes in landscape pattern (Figure 5-3 shows a comparison of two alternatives).

EAM requires three classes of input data, (1) a detailed habitat map and (2) the species density response to habitat type and (3) distance from edges. EAM is a raster-based spatial model that is created by applying the animal density response to the closest patch edge. The EAM then provides a rapid, automated means of assessing effects of shifts in patch size, shape, and edge characteristics, given a relatively small set of assumptions regarding species' response and the spatial relationship of its habitat.

Strengths

This model incorporates habitat and species density response information into one program for analysis. The program calculates the species' density and abundance response to the habitat given, and can therefore be used to assess impact of habitat change in a given species. However, this is provided one has habitat data for a time series or can manipulate habitat data to generate habitat change information.

The program can also "remove noise" from the habitat data. This function allows the user to remove habitat patches that are smaller than the user-specified area or number of pixels, and replace them with values of the patches' nearest neighbors. EAM can also classify "no data" fields to values of their nearest neighbors.

The program is able to calculate empirical error through calculation of confidence intervals. Error of the animal density grid is calculated to a user-specified confidence interval, assuming the response variable is distributed normally.

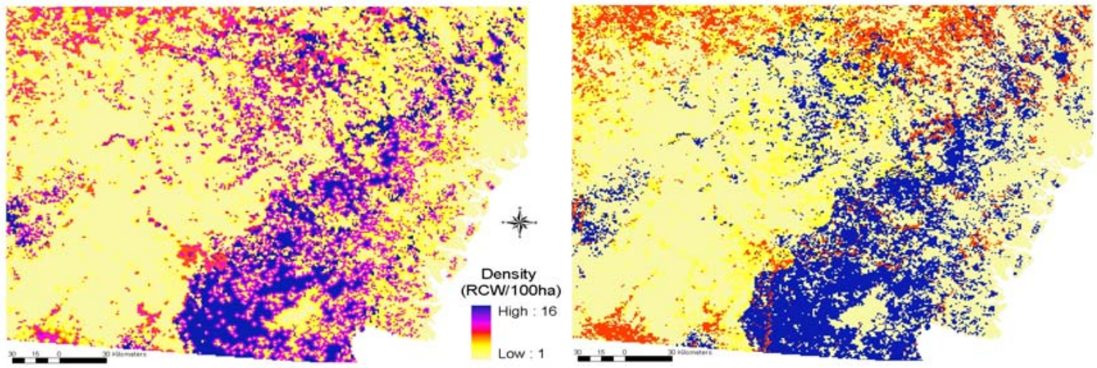

Figure 5-3. Example of EAM density grids using the edge response and no edge response (null) models for the red-cockaded woodpecker near Fort Stewart, GA.

Shortcomings

The program emphasizes "effective area," which is a generalized version of the core area concept. Although this generalization is very useful, effective area (or core area) is only one factor that determines TES persistence in a landscape. Other factors (species' vital rates, predation, competition, climate, etc.) are not considered. Also, EAM assumes the habitat is static; it does not incorporate habitat dynamics (a general limitation of habitat suitability models).

Unlike some other methods of habitat suitability modeling, EAM requires prior definition of "patch" and identification of "edge." Other methods (such as HSI, or the more general methods of habitat modeling) do not require this, but if such information is available, these more general methods can be used to estimate the same functions (e.g., of distance to edge) that EAM uses.

Another shortcoming is that, unlike more general habitat modeling methods, EAM does not estimate the parameters of the function (e.g., based on occurrence data). Thus, using EAM requires using these more general methods (such as logistic regression) to estimate the parameters to enter in EAM. Although these inputs make logical sense, there is little fieldwork to support their generation for the EAM.

General Evaluation of the Models in Relation to Military Lands Management

The reviewed models can be grouped in four categories (Table 5-2).

Table 5-2. Characteristics of fragmentation models.

	Index methods	Habitat suitability models	Landscape prediction models	Species viability models
Evaluated models	FragStats r.le Patch Analyst (HAMS)	HSI HAMS EAM	CURBA LTM LUCAS	RAMAS GIS DIAS RCW

Index Methods

The methods in this category (FragStats, R.L.E., Patch Analyst) calculate a variety of patch and landscape-level metrics or statistics that characterize the spatial structure of the landscape. These metrics include measures of area (e.g., mean patch size), shape (e.g., fractal dimension), isolation (e.g., nearest neighbor distance), and other attributes of predefined patches (of specific types) distributed in a landscape. The three programs do a very good job of making these calculations relatively easily. A fourth program (HAMS) also calculates some landscape metrics, but it is reviewed below under habitat suitability models. However, there are four primary shortcomings of the index methods as tools for analyzing the effects of habitat fragmentation:

1. The index methods are based on predefined patches or habitat categories, which require a habitat analysis for the species and considerations of the species' behavioral characteristics (territoriality, home range, dispersal, etc.) that affect its use of space.
2. Index methods describe the structure of the landscape, but do not analyze the effects of habitat structure on floral or faunal species. The relationship between the metrics reported by the index methods, and the biological response of the species must be quantified using other methods (such as PCA, or regression).
3. The types of analysis described above can be used to find relationships between landscape metrics and population responses, but it is difficult, if not impossible, to use these relationships for prediction (e.g., of future population responses in the same landscape, or in another landscape).
4. The index methods are static; they do not consider or model temporal dynamics (e.g., changes in land use).

Habitat Suitability Models

The methods in this category (HSI, HAMS, EAM) are used to predict a species' response to its environment, including the landscape it lives in. The response is usually the occurrence or abundance of the species at a certain locality or the carrying capacity of the habitat. The model is usually in the form of an equation that relates this response to various habitat-related variables. These variables can include landscape metrics, as well as other variables that determine the suitability of the land as habitat for a particular species (such as elevation, basal area for particular tree species, distance from roads, distance from water, etc.). The model is often used to calculate a habitat suitability map for the species.

Unlike the three index methods evaluated above, these three methods differ from each other, as well as from other habitat suitability models that were not evaluated. The HAMS model is based on pattern recognition (PATREC) method, which is not widely used and can lead to over-fitting. The EAM model can be useful in the limited context of edge effects, but other, more general habitat suitability models can also incorporate such effects. In addition, the HAMS and EAM models are not widely used, and there are very few examples of their application. Thus, these models are not recommended.

The HSI method is widely used, very simple and straightforward. However, the variables selected for inclusion in the HSI model, and the shape of the function for each variable, are usually based on expert opinion and can therefore be subjective. In addition, the form of the function is restrictive and arbitrary, does not readily allow for interactions between variables, and often requires assumptions of linearity between a habitat variable and the species' response to the variable.

These particular shortcomings of the HSI model can be reduced or eliminated by the more quantitative and objective methods of habitat modeling, such as general linear models (e.g., logistic regression, also known as resource selection function, rsf). These statistical procedures use species occurrence or abundance at each location as the dependent variable and the habitat characteristics as the set of predictive variables. Most statistical methods require both presence and absence data, while others (such as "climatic envelopes") require only presence data (Elith 2000).[71] The ad-

[71] Elith, J. 2000. "Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants." Pages 39-58 in Ferson, S. and Burgman, M. (eds), *Quantitative Methods for Conservation Biology.* Springer-Verlag, New York.

vantage of these statistical habitat suitability models over the HSI model is that they are statistically rigorous and can be validated; they can also incorporate nonlinearities of, and interactions among habitat variables.

Because the habitat suitability models relate features of the landscape to its use by particular species, their output (habitat functions or habitat maps) are relevant for the questions related to managing lands, particularly for studying the effects of fragmentation on TES. The models that are based on statistical methods are especially relevant, because they are objective, and can be validated. These models can be used to estimate habitat functions (and to create habitat maps) at different time steps, provided that both landscape data (maps of land cover, etc.) and occurrence data are available for multiple time steps. Such time series of habitat maps can be used to monitor the change in species' habitat.

The fundamental shortcoming of all habitat suitability models is that they describe habitat suitability, but they do not predict the viability or persistence of the species in that habitat, because viability also depends on factors other than habitat suitability, including landscape-level factors (e.g., expected future change in the amount and spatial distribution of habitat) and demographic factors (survival, fecundity, and dispersal as functions of habitat; exploitation and other impacts not related to habitat, etc.). In other words, habitat suitability is only one component of viability; it cannot be used by itself to predict the effects of fragmentation on the future persistence of TES in a given landscape. Thus, it is recommended that statistical models of habitat suitability (especially logistic regression) be used in combination with viability-based methods.

Another important shortcoming of habitat suitability models is that they treat habitat as a static component, and do not incorporate dynamic changes in the landscape. Depending on the landscape, and the specific fragmentation question to be addressed, this may be an important shortcoming. For those cases where the temporal change in the spatial structure of the habitat is important, general models of habitat suitability can be (and have been) linked to landscape models (described below).

Landscape Prediction Models

Landscape prediction models aim at predicting the future of a landscape in terms of land use and land cover. Thus, they do not directly predict impacts on TES, but by combining them with habitat models (above) and viability models (below), the effects of landscape change on TES can be evaluated. However, this has been done only to a limited extend.

The three reviewed landscape prediction models (CURBA, LTM, and LUCAS) belong to a large group of at least 20 models (most of them recently reviewed by Agarwal et al. 2002).[72] In general, these models focus on urban growth and other forms of human land use, but do not include much biological detail. For example, the natural vegetation is often categorized into very broad classes such as "forest" or, at most, "deciduous forest." This lack of specificity means that these models cannot be used to predict the effects of human land-use on specific TES.

Another group of landscape models focuses on predicting the changes in structure and composition of the vegetation cover or more general changes in classes of land cover. In general they include more biological detail than landscape models that focus on human land-use. However, the models that focus on natural vegetation dynamics have limited capabilities for incorporating human activities other than timber harvest. Thus, they do not explicitly recognize and integrate land-use changes, particularly increasing urbanization.

Because they include more detail on vegetation structure, these models have previously been linked to habitat suitability models for particular species, including TES (Smith 1986; Davis and DeLain 1986; Hyman et al. 1991; Pausas et al. 1997; Curnutt et al. 2000; Akçakaya et al. 2003).[73] Such links between landscape and habitat suitability models eliminate one of the shortcomings of habitat models (static landscape). However, the more important shortcoming of lack of direct relevance to persistence requires links with species viability models discussed below.

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[72] Agarwal, C., G. M. Green, J. M. Grove, T. P. Evans, and C. M. Schweik. 2002. *A review and assessment of land-use change models: dynamics of space, time, and human choice*. Gen. Tech. Rep. NE-297. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 61 pages. Available at: http://www.srs.fs.usda.gov/pubs/.

[73] Smith, T.M. 1986. "Habitat-simulation models: integrating habitat-classification and forest- simulation models." Pages 389-393 in J. Verner, M. L. Morrison, and C. J. Ralph, editors. *Wildlife 2000: modeling habitat relationships of terrestrial vertebrates*. University of Wisconsin Press, Madison. Davis, L.S., and L.I. DeLain. 1986. Linking wildlife-habitat analysis to forest planning with ECOSYM. Pages 361-369 in Verner, J., M.L. Morrison and C.J. Ralph (eds.) *Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*. University of Wisconsin Press, Madison. Hyman, J., J. McAninch, and D.L. DeAngelis. 1991. "An individual-based simulation model of herbivory in a heterogeneous landscape." Pages 443-478 in M.G. Turner and R.H. Gardner, editors. *Quantitative methods in landscape ecology*. Springer-Verlag, New York. Pausas, J.G., M.P. Austin, I.R. Noble. 1997. "A forest simulation model for predicting eucalypt dynamics and habitat quality for arboreal marsupials." *Ecological Applications* 7: 921-933. Curnutt, J.L., J. Comiskey, M.P. Nott, and L.J. Gross. 2000. "Landscape-based spatially explicit species index models for everglades restoration." *Ecological Applications* 10: 1849-1860. Akçakaya, H. R., J. L. Atwood, D. Breininger, C. T. Collins, and B. Duncan. 2003. "Metapopulation dynamics of the California least tern." *Journal of Wildlife Management* 67(4):829-842.

Species Viability Models

These population or metapopulation models simulate the dynamics of a species and predict its future in terms of number of individuals, risk of decline or extinction, and chance of recovery. Species viability models are based on population-level ecological models, including structured (life history, or matrix) models, individual-based models, and metapopulation models (Pastorok et al. 2002)[74]. From the point of view of evaluating the viability of species under fragmentation, the relevant types of population-level models are stochastic models with explicit spatial structure.

Several such models are implemented as generic computer programs, including RAMAS GIS, Vortex, and ALEX. Lindenmayer et al. (1995)[75] reviewed earlier versions of these programs. RAMAS GIS allows an explicit link to GIS software and incorporates dynamic spatial structure, including appearing, disappearing, merging, and splitting patches (Akçakaya 2001, 2002).[76] RAMAS GIS also links the habitat suitability models discussed above to a species viability model. The habitat suitability model can be of a variety of types, including HSI model, or more general models such as logistic regression. However, the program does not estimate the habitat model; the user must enter the habitat model as a function.

Species viability models that have explicit spatial structure directly relate to the question of the persistence of a species in a fragmented landscape; thus, they are relevant to the issues related to managing lands. In addition, they can be used in a temporal manner to follow changes over time, and they can recognize and integrate land-use changes such as urbanization, if such changes are input as a time series of maps. However, species viability models do not predict such maps (RAMAS GIS can use such predictions as input) if they are exported as a set of time series raster maps describing the habitat variables that are used in the user-specified habitat suitability function. Thus, species viability models can be linked to landscape models by using the output of a landscape model as input for a spatially explicit (and spatially dynamic) viability model. An example of how such a link can be formed is a

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[74] Pastorak, R. A., S. M. Bartell, S. Ferson, and L. R. Ginzburg, editors. 2002. *Ecological Modeling in Risk Assessment: Chemical Effects on Populations, Ecosystems, and Landscapes*. Lewis Publishers, Boca Raton, Florida.

[75] Lindenmayer, D. B., Burgman, M. A., Akçakaya, H. R. and Possingham, H. P. 1995. A review of generic computer programs ALEX, RAMAS/space and VORTEX for modelling the viability of wildlife metapopulations. Ecological Modelling 82: 161-174.

[76] Akçakaya, H.R. 2001. “Linking population-level risk assessment with landscape and habitat models.” *Science of the Total Environment* 274:283-291. Akçakaya, H.R. 2002. “Estimating the variance of survival rates and fecundities.” *Animal Conservation* 5:333-336.

new program, RAMAS Landscape, which links the forest landscape dynamics model LANDIS to RAMAS GIS. This program integrates landscape and metapopulation approaches, allowing the modeling of species viability in a dynamic landscape.

Applying a Viability Fragmentation Model to the Evaluation of Golden-cheeked Warbler Habitat

Objective

The golden-cheeked warbler (GCW, *Dendroica Chrysoparia*) is an endangered neotropical migrant songbird with one of the most restricted breeding ranges in all of North America. Within the United States, it nests only in Texas. In 1990, the GCW was placed on the Federal endangered species list due to declines in population, reductions of overall range, and continuing loss of nesting habitat (U.S. Fish and Wildlife Service 1992).[77]

The objective of this study was to demonstrate the use of habitat-based metapopulation modeling in evaluating the impact of habitat loss and fragmentation on the long-term persistence of the GCW. Two very simple fragmentation scenarios were given to demonstrate this approach.

Fragmentation Scenarios

Habitat fragmentation was modeled by reducing the amount of available habitat every 5 years for a period of 50 years. Two scenarios of habitat loss, low and high, were modeled to compare the effects of different levels of habitat encroachment. Future habitat loss is difficult to predict; however, areas currently developed were assumed likely to experience further expansion. Therefore, fragmentation was modeled as a function of the distance of the habitat from cities and highways.

A habitat suitability function was created that links habitat characteristics to a measure of habitat suitability. For this model, the proximity of a cell to the nearest city and highway was used as a habitat characteristic that influences suitability. Habitat within a specified distance, X meters, from a city or within a distance of 2X from a city and within 1 km of a highway was considered unsuitable (i.e., habitat

[77] U.S. Fish and Wildlife Service (USFWS). 1992. Golden-cheeked warbler recovery plan. USFWS, Endangered Species Office, Albuquerque, NM. 88pp.

value = 0). To model temporal changes in habitat, a time series of habitat maps was created where the distance X was increased every 5 years. For low habitat loss, the distance X was increased in 150-m increments from 0 to 1,500 m. In high habitat loss models, X was increased in 1,000 m increments from 0 to 10,000 m. Simulations were also run without habitat loss and the results were compared.

It was assumed that habitat loss and fragmentation affected only available habitat as reflected in the number, location, and carrying capacities of the habitat patches. The locations of habitat patches determine their distances to neighboring patches, thus affecting dispersal rates. Other aspects of the species demography (in particular survival rates and fecundities) were assumed to be unaffected by habitat loss and fragmentation.

Analysis and Viability Measures Used

The analysis of the dynamics of the golden-cheeked warbler metapopulation consisted of a series of simulations. Each simulation consisted of 1,000 replications, and each replication projected the abundance of each population for 50 years.

To analyze the sensitivity of the model results to parameters, three simulations were run for each parameter, using the lower, intermediate, and upper estimates of that parameter and medium estimates of all other parameters. Two measures were used to express the predicted viability of the metapopulation:

1. Risk of 85 percent decline in metapopulation abundance and
2. Risk of falling below the metapopulation threshold of 5,000 birds anytime within 50 years.

Results

Patch structure

Nineteen patches were found in the simulations based on an average territory size of 6.7 ha. Total carrying capacity (K) was 47,246. Using a lower estimation of K resulted in delineation of 10 patches and a total carrying capacity of 16,395. In both models, the largest patch made up about 75 percent of the total area of all patches and the two largest patches together made up about 98 percent.

Carrying Capacity (K)

The results of simulations with different carrying capacities were similar. There was no significant difference in percent decline between the low and high carrying capacity models. In absolute numbers, the low K models declined to a smaller population size than in the high K models due to the smaller initial population size in the low K models.

Dispersal

The major effect of dispersal was on metapopulation occupancy. Using medium values for all other parameters, at the end of the 50-year simulations 5.4 ± 2.1 (mean ± s.d.) populations were occupied in the low dispersal model and 6.4 ± 2.5 were occupied in the high dispersal model. The population trajectory and extinction risk did not significantly differ between the low and high dispersal models (Kolmogorov-Smirnov test; D = 0.033, p = 0.65).

Correlation

The correlation among vital rates of populations had a more pronounced effect on the risk of decline. Under the assumption of medium values for all other parameters, the risk of 85 percent decline was 0.1540 and 0.2130 for low and high correlation, respectively. The risk of declining below a population abundance of 13,000 was greater in the high correlation model than the low correlation model (Figure 5-4). However, the risk of decline to an abundance between about 13,000-30,000 was greater in low compared to high correlation models. The risk curves for low and high correlation models were significantly different (Kolmogorov-Smirnov test; D = 0.082, 7p = 0.0024).

Habitat fragmentation

The habitat fragmentation scenarios resulted in a reduction in the amount of available habitat. In low habitat loss, about 8.6 percent of the habitat area was lost, and in high habitat loss about 48 percent was lost. Using medium values of carrying capacity, dispersal, and correlation parameters, the mean abundance after 50 years was 10,724 for no habitat loss, 9,897 for low, and 5,355 for high habitat loss. The habitat loss that occurred also resulted in a greater number of populations, with a mean metapopulation occupancy at the end of the 50-year simulations of 6.2 for no habitat loss, 8.1 for low, and 48.8 for high habitat loss.

The fragmentation of habitat resulted in a greater risk of decline. The probability of metapopulation abundance declining by 85 percent within 50 years was 0.1850, 0.2010, and 0.3190 for no, low, and high habitat loss, respectively.

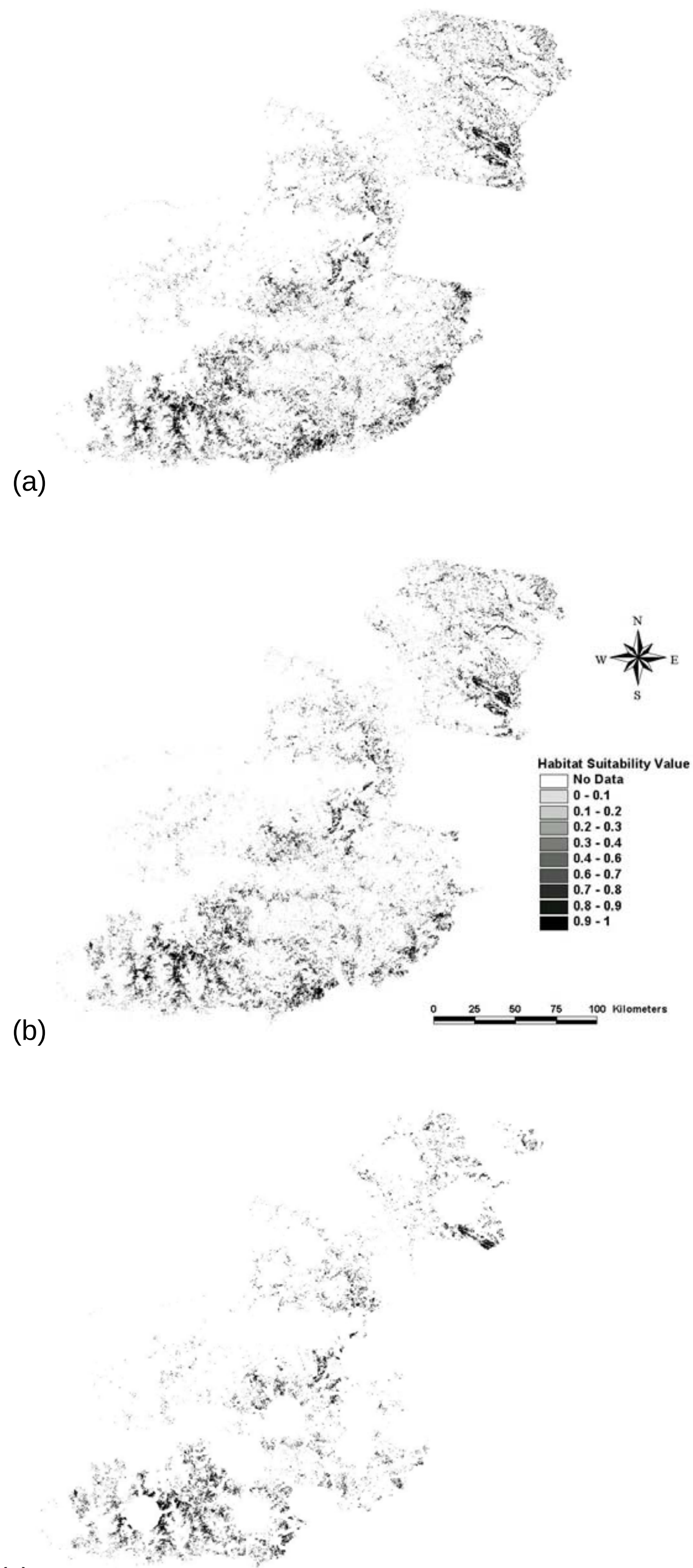

Figure 5-4. Distribution of golden-cheeked warbler habitat after 50 years under fragmentation scenarios of (a) no habitat loss, (b) low habitat loss, and (c) high habitat loss.

The carrying capacity used in the model affected the percent decline in abundance for some models. For no habitat loss and low habitat loss, the percent decline did not significantly differ between low and high carrying capacity models. There was a significant difference in percent decline between the low and high K models for the high dispersal models with high habitat loss. Percent decline was similar for no habitat loss and low habitat loss and higher in high habitat loss models.

The risk of decline of the species to 5,000 birds within the next 500 years was different under different carrying capacities and dispersal and correlation functions. The low carrying capacity models had a higher risk than the high carrying capacity models. For low carrying capacity models, risk of decline was greatest in high habitat loss scenarios and the range in the risk of decline was similar for no and low habitat loss scenarios. Under no habitat loss, the low correlation models had a lower risk than high correlation models (Figure 5-5).

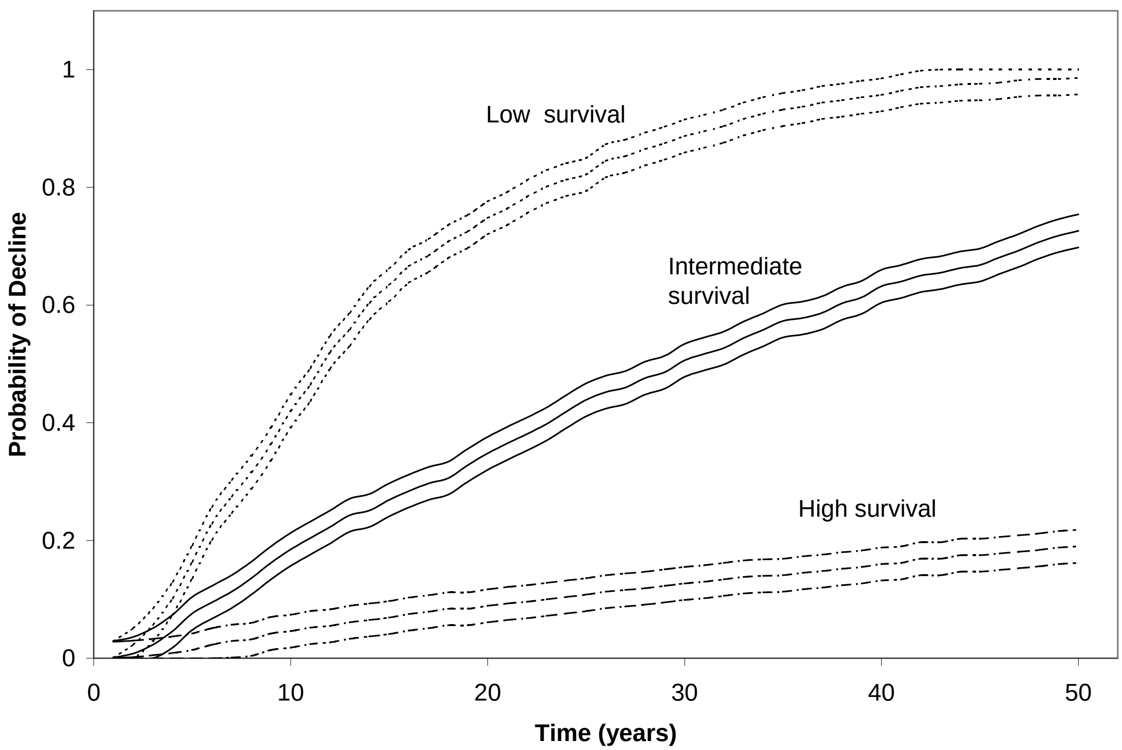

Figure 5-5. Sensitivity of risk of decline to hatch year survival.

In the high carrying capacity models, the risk of declining to less than 5,000 birds ranged from 0.4330 to 0.5660 for no loss, 0.4540 to 0.5750 for low loss, and 0.5010 to 0.7570 for high habitat loss. In all three habitat loss scenarios, the lowest risk occurred with low dispersal and low correlation parameters. Under the two fragmentation scenarios, the high dispersal and high correlation parameters resulted in the greatest risk.

The results showed sensitivity to the estimates of fecundity and survival. Risk of decline to 5,000 birds in 50 years ranged from 0.9970 to 0.0790 for low and high Hatch Year (HY) fecundity estimates (Figure 5-5) and from 0.9200 to 0.2370 for low and high Annual Hatch Year (AHY) fecundity. Risk ranged from 0.9860 to 0.1900 for HY survival. The results were not sensitive to density-dependent dispersal.

Discussion

The spatial structure derived depends on the accuracy of the habitat map. The habitat map used is based on vegetation classification from TM satellite imagery, with no verification conducted on the ground. The actual occurrence of golden-cheeked warblers in areas classified as habitat or non-habitat is therefore unknown. Areas may have been misclassified due to the nature of TM imagery, the inability to recognize habitat variables such as tree age, and difficultly distinguishing between woodland and savanna. Due to these limitations, the classification of land cover into 'habitat' and 'non-habitat' is believed to be about 80 percent accurate (Diamond and True 1999). The accuracy of the map will influence the habitat suitability function, recognition of patches, carrying capacity, and initial abundance.

The selected fragmentation scenarios were based only on the distance from roads and cities. Future fragmentation is difficult to predict, as it undoubtedly depends on many other factors, including social and economic ones. Thus, future fragmentation assessments like this study must be considered only as "what if" projections, rather than forecasts of future conditions.

An important aspect of evaluating the impact of habitat loss and fragmentation is determining the model parameters that will be affected. In this study, habitat loss and fragmentation affected several model parameters, including distances among populations (which determine dispersal rates and spatial correlations), number of populations, and carrying capacities of populations. Other aspects of the species demography (in particular survival rates and fecundities) were assumed to be unaffected by habitat loss and fragmentation. This may not be a valid assumption. Increased fragmentation may cause increase edge effects (because each habitat patch is smaller; therefore a larger proportion of each habitat patch is closer to an edge between the habitat patch and the surrounding landscape). Edge effects may result in lower survival and fecundity. Such effects can be documented only through comparative field studies that allow multi-annual estimation of survival and fecundity in habitat patches of different sizes. In the absence of such data, it was assumed that these effects did not exist. Despite this optimistic assumption, the results indicate that loss of habitat around existing roads and cities may cause substantial decrease in long-term viability of this species.

The sensitivity analysis conducted gives information about which parameters need to be estimated more carefully. The results were extremely sensitive to both survival and fecundity estimates. High vital rates were estimated from Fort Hood, where active management strategies are in place. This estimate may therefore be overly optimistic for the entire habitat range. Improved estimates of vital rates and their association with habitat quality would greatly improve future models and therefore management decisions.

The sensitivity of the results of this work suggests the results should not be interpreted in absolute terms. The model serves as a way to compare possible fragmentation and management scenarios and not as a way to predict future abundance in absolute numbers. Results from sets of possible scenarios can be compared in relative terms to evaluate management options.

Despite the high sensitivity of the results to some parameters, the predicted effect of habitat loss was robust to uncertainties in the model. Under any combination of uncertain model parameters (such as vital rates, dispersal, or correlation functions), low habitat loss resulted in higher viability than high habitat loss. For example, under both low and high dispersal rates, the high habitat loss results in higher risks. Thus, even if the precise value of some model parameters were unknown, habitat fragmentation scenarios can still be compared or ranked with respect to their effect on the viability of the GCW.

The model results (the effect of habitat loss) are also robust with respect to vital rates, despite the fact that fragmentation may affect average vital rates (because of edge effects). The reason is that any expected affect of fragmentation on vital rates will more likely increase the difference between low and high habitat loss than decrease the difference.

Implications for Military Land Managers

Although the GCW demonstration application was carried out with many restrictions, it reveals the utility of such modeling efforts to the management of military TES habitats. Restrictions included:

- Little data availability on the TES except that which was in the published literature. Installation managers usually have access to a good deal of additional information through unpublished data and institutional knowledge. Therefore, many of the variables estimated in this example can be improved upon significantly.
- Little data availability about the landscape beyond the installation lands except that which was available at a national level. Unfortunately, this is a common current situation. The only means to refine this is through the ma-

nipulation of remote sensing data such as the TM data used in the example. As mentioned, the development of a habitat map in conjunction with other data (e.g., topography, hydrology, etc.) and ground truth from the installation would have further refined the analysis. Even without these additions, the habitat map generated based on the imagery was estimated to be 80 percent accurate.

From an effort like this, a land manager can learn:

- What the likely future scenario for the installation TES(s) is (are). Significantly, a land manager can see the value of funding various options available. If under all possibilities, there is a low possibility of a viable TES population on the installation, the manager knows how well spent those funds are on the installation (versus for projects off installation).
- What the relative importance of trying to influence changes in TES characteristics are. From the model, it is clear that it is important for the manager to try to influence survival and fecundity.
- Those objections to the effect that “not everything is known about a particular TES so we cannot trust models based on incomplete data” are immaterial to the military land manager for purposes of resource allocation. It is important to focus on the consequence that the predicted result to the model habitat loss was robust to the uncertainties. If so, why would a land manager provide resources to work that would not significantly change the nature of the resultant scenario?
- What locations off the installation will provide for him the greatest return for his effort when involved in the ACUB process. A well carried out viability analysis will also provide an objective relative ranking of the importance of different land parcels. That ranking can translate easily into the number of dollars that would be appropriate to expend in support of land conservation efforts, making financial decisions easier to defend and helping to direct ACUB dollars toward the most appropriate lands.
- Cooperation that might be required from other agencies and stakeholder to accomplish the mission of habitat preservation within installation boundaries is more easily justified. Also as a corollary, the support and cooperation of higher levels within the military are more easily justified if the cooperation is more appropriately carried out at those levels (e.g., if the habitat crosses international boundaries).

Conclusions and Recommendations

The major concerns that have emerged from this review of the issues of TES habitat fragmentation (as they concern the Army military mission) lead to the following conclusions:

1. There are a number of fragmentation evaluation programs and models currently available. Although they present different approaches, all of them also fundamentally rely on some version of standard landscape metrics originally pioneered in a program called FragStats. Since this set of landscape metrics provide the core for most programs, they then must be considered as the basis for the direction toward which future research must be aimed.
2. Although researchers have developed a plethora of TES habitat and viability models, all of them suffer from the inability to get required support data. The field data does not well fit into the structure of the technology that has been developed for the 21st century. It is likely that a major paradigm shift has occurred in the way science is now being done and this change has not yet been recognized in our funding and review structure.

Therefore, it is recommended that:

1. The research community more closely determines what is actually needed to manage TES at a regional scale and then set in motion research to provide the answers that will generate the information Army land managers need to carry out for their TES management and recovery requirements.
2. The Army sponsor a conference of TES biologists and modelers to improve the efficiency and effectiveness of the TES research program. The purpose would be to coordinate efforts of the two groups. Desired results of the conference would be:
   a. Biologists would agree among themselves on the basic critical characteristics for a viable habitat for each TES. These characteristics will be required to be in a format that can be measured in the field and successfully summarized as critical TES parameters.
   b. Modelers would agree among themselves on the basic critical inputs they must have to successfully operate their models. These inputs will be required to be in a format that can be measured in the filed or derived.
   c. Both groups would agree on the critical parameters that each could discuss with the other group. This result should set the direction for coordinated initial research.
   d. Both groups would identify the critical parameters that are required but are not available for field measurement and verification at this time. This result should set the direction for coordinated long-term research.

6 Data Quality for Themes Monitoring Threatened and Endangered Species Habitat

Dr. Charles Ehlschlaeger

Overview

This chapter describes the quality and utility of data products useful to the identification and long-term monitoring for Threatened and Endangered Species (TES) habitat. Chapter 3 of this report discusses data themes and a basic modeling procedure for identifying TES habitat. Chapter 7 of this report (page 146) discusses data themes and models necessary for long term monitoring of TES habitat.

Ideal data products useful in modeling TES habitat provide a highly accurate baseline as well as frequently renewed time-series themes for long-term monitoring. Ideal data products will also be available from global or national sources. Data from local governments, such as cities or counties, has two major problems:

- Local government data sources have large variability in data standards and quality, and some local governments in the study area may not even have the data in an appropriate format.
- Combining data from different local government entities is a logistical nightmare and will severely increase the overall cost of the monitoring program.

Therefore, while data themes from local government are useful for monitoring TES habitat, they will provide less benefit for more effort than other data themes.

Unfortunately, there is no straightforward technique to define the quality of data. Data quality cannot be determined independent of the use to which that data will be applied. Since the goal is too determine TES habitat, the important issue is whether these data layers can provide a useful model of TES habitat. There are drawbacks to determining the usefulness of TES habitat models.

1. Few TES have been researched enough to definitely determine (or even roughly determine) the number of individuals that are capable of living within regions defined as "quality habitat", "good habitat," or "marginal habitat."
2. None of the TES have been researched enough to definitely determine the boundaries between TES habitat and nonhabitat.
3. The national data products are not precise or accurate enough to locate the boundaries between habitat and non-habitat with complete confidence.

Given that it is currently not possible to use these data layers to define an accurate count of TES individuals within a region, one needs to recognize instead that data models can provide a representation of which lands are more suitable than others for the goal of identifying and monitoring TES habitat. Therefore, at this time, the initial goal of a TES habitat modeler is to rate the relative potential tracts of land for specific species in support of potential ACUB program purchases. Once local species counts have been made, it is then appropriate for monitoring data layers to be used to measure stresses on TES habitat (as well as improvements to the habitat).

This chapter provides a description of data quality for many products identified as useful for TES habitat modeling. Each data product will be discussed in a separate section. Each section will contain a brief summary of the data's utility followed by a description of quality. The chapter concludes with caveats and advantages of that data product for modeling TES habitat.

Potentially Useful Data Products

Products Available Now

1. The 30-m resolution National Land Cover Data (NLCD) to model:
- large tracts of mixed deciduous and coniferous tree cover,
- coniferous tree cover,
- deciduous tree cover,
- protective canopy flight corridors,
- large bodies of water,
- shrub cover and nectar corridors,
- "Fragmented places."

2. MODIS (between 30°S and 30°N and soon for much of the rest of the world): quarterly land cover map (MOD44A, Level 3 96-day land cover / dynamics) to model:
- recent land use change that has occured,
- recent urbanization and orchard growth tha has occurred,

- protective canopy flight corridors, and
- when MODIS has been around for 20+ years, it can be used to measure tree stand age.

3. FSCPP county level population growth estimates to determine population density for various locations (using NLCD as a model of land cover type). As population density increases, use population change to model habitat loss.

4. National Elevation Data to model:
- steep canyon slopes,
- rough terrain,
- elevations 900-1,500m,
- flat and rolling hills.

5. U.S. census block population counts for population density.

6. MODIS LST (MOD11) product potentially to monitor surface soil moisture. (Caveat: More validation of MOD11 is necessary before this surface soil moisture data is useful.) MOD11 can be used to model:
- moist soil to ensure adequate water supplies,
- potential fire hazard.

7. Soil Survey Geographic DB (SSURGO) for:
- high surface runoff,
- deep, well-drained, sandy substrate at least 1m above the seasonal water table.

8. MODIS 8-day L3 fire product (low quality): can be used to locate current fires.

9. TIGER files to locate large bodies of water.

10. MODIS leaf area index can locate places with too little undergrowth.

11. EPA STORET water quality information: http://www.epa.gov/storet/about.html. Water quality information can be found at NWISWeb at: http://waterdata.usgs.gov/nwis

Products Available Soon

1. The Future MODIS 500m 32-day burned area product will provide a more accurate history of burned area.

2. MODIS Vegetation Continuous Field Maps (MOD44B, 500m current, 250m resolution with Collection 5 data[78]) presents percent grasses and shrubs, as well as percent trees to determine prime habitat to model:

- canopy cover,
- sunny grassy areas,
- noncontinuous canopies,
- percent shrub cover,
- areas with enough grasses and shrubs for Palmer's agave, and enough bare ground to prevent fires from getting too hot,
- rangeland clearing (a drop in forest cover would indicate an increase of cowbirds),
- overbrowsing of nearby rangeland (a drop in grass cover with increased bare ground).

Data Quality by Theme

30-m resolution National Land Cover Data

NLCD can be used to model the following important concerns for the indicated TES of high Army concern:

- large tracts of mixed deciduous and coniferous tree cover (golden-cheeked warbler)
- coniferous tree cover (gopher tortoise, red-cockaded woodpecker)
- deciduous tree cover (black-capped vireo)
- protective canopy flight corridors (gray bat, Indiana bat)
- large bodies of water (gray bat, Indiana bat)
- shrub cover and nectar corridors (lesser long-nosed bat)
- "fragmented places" (brown-headed cowbird).

NLCD data was created by the Multi-Resolution Land Characteristics (MRLC) Consortium. The MRLC Consortium contains 9 federal agencies that purchased 1993 Landsat 5 imagery for the lower 48 states. This first generation product is now freely available for download at http://landcover.usgs.gov/. The second generation NLCD is currently being created from 2001 Landsat images and is slowly becoming available for the entire continental United States.

[78] As the NASA EOS data manipulation routine is refined, the data is reprocessed with a higher collection number. Collection number 3 is currently available; they are working toward greater Product Validation.

EPA has performed an accuracy assessment of the NLCD by dividing the 48 states into the nine EPA regions and calculating the "user's accuracy" for each NLCD class within each region. There are three EPA regions relevant to the TES in this report:

- Region Four (states south of and including Kentucky and North Carolina),
- Region Six (New Mexico, Texas, Oklahoma, Arkansas, and Louisiana), and
- Region Nine (California, Nevada, and Arizona).

User's accuracy is a measure of how likely a cell with a desired land cover class is actually the class desired. User's accuracy was sampled at both Level One and Level Two of the classification scheme (after Anderson[79]).

Level One classification breaks land cover into broad categories:

- open water (10s),
- urban (20s),
- forest (40s),
- grasses and shrub (50s and 70s),
- croplands (60s and 80s), and
- wetlands (90s).

Level One classification important for modeling TES includes:

- grasses and shrubs (50s and 70s) for "shrub cover and nectar corridors."

Level Two Classification provides a more precise breakdown of land cover classes than Level One classification. The Level Two classes in the NLCD are:

- open water (11),
- perennial ice/snow (12),
- low-density residential (21),
- high-density residential (22),
- commercial/industrial/transportation (23),
- bare rock/sand/clay (31),
- mining (32),
- transitional (33),
- deciduous forest (41),
- evergreen forest (42),
- mixed forest (43),
- shrubland (51),
- orchards/vineyards (61),

[79] Anderson, J.F., E.E. Hardy, J.T. Roach, and R.E. Witmer, 1976. *A Land Use and Land Cover Classification System for Use with Remote Sensor Data*, Professional Paper 964, U.S. Geological Survey, Washington, D.C., 28 p.

- grasslands (71),
- hay and pasture (81),
- cropland (82),
- small grains (83),
- bare soil/fallow land (84)
- urban grass (85),
- woody wetland (91), and
- emergent (herbaceous) wetland (92).

Land cover classes important to modeling TES habitat include:

- mixed forest (43), woody wetland (91), and evergreen forest (42) for "large tracts of mixed deciduous and coniferous tree cover,"
- deciduous forest (41), mixed forest (43), woody wetland (91), and evergreen forest (42) for "protective canopy flight corridors,"
- evergreen forest (42) for "coniferous tree cover,"
- deciduous forest (41) for "deciduous tree cover,"
- open water (11) for "large bodies of water."

We can determine the quality of NLCD data for the purpose of identifying TES habitat by analyzing the EPA's NLCD data quality research. The EPA performed a stratified random sample of NLCD classes throughout the 10 EPA Regions comprising the 48 states. The NLCD classes were compared to the georeferenced higher quality National Aerial Photography Program (NAPP) photos.

Figure 6-1[80] compares a Landsat image used to create NLCD land cover classes to the NAPP photograph to determine NLCD quality.

The likelihood of NLCD classes actually being the desired category is summarized by Table 6-1 and Table 6-2. For both tables, each cell contains the likelihood that any given NLCD class is actually a NAPP class at that location. The three numbers represent EPA Region Four, Six, and Nine, respectively. For example, in Table 6-2 an NLCD Deciduous Forest, value 41, pixel in Georgia (EPA Region Four) has a 0.4 percent chance of really being class 21, a 7.6 percent chance of really being class 33, a 63.8 percent chance of being class 41, a 19.4 percent chance of really being class 43, a 1.8 percent chance of really being class 81, a 0.9 percent chance of really being class 82, a 3.1 prcent chance of really being class 85, a 1.8 percent chance of really being class 91, and a 0.9 percent chance of really being class 92.

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[80] From http://landcover.usgs.gov/accuracy

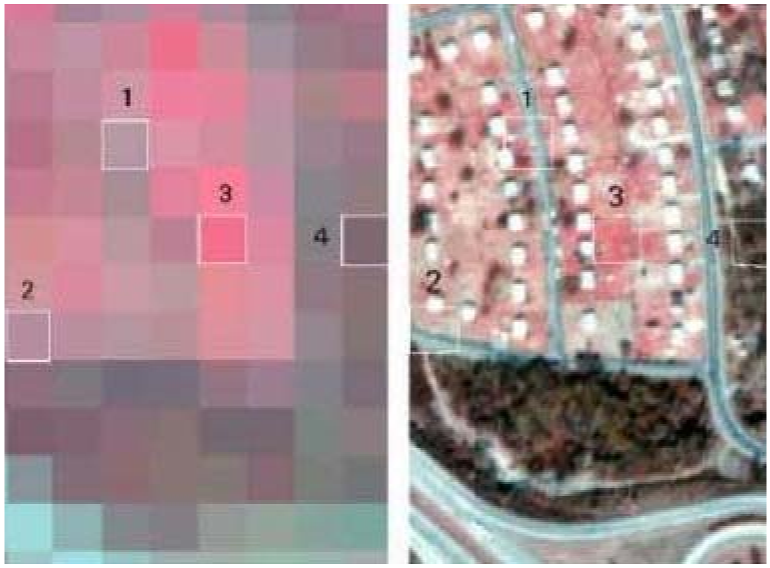

Figure 6-1. Landsat image used to make NLCD (left) to a NAPP photo (right).

Table 6-1. Percent classified and percent correctly classified (bold) for NLCD Level One.

	NAPP Water (10s)	NAPP Urban (20s)	NAPP Transition (30s)	NAPP Forest (40s)	NAPP Grasses and Shrubs (50s and 70s)	NAPP Croplands (60s and 80s)	NAPP Wetlands (90s)
NLCD Forest (40s)	.2%, .2%, -	1.1%,1.2 %, .2%	2.2%, 2.0%, 2.1%	**90.7%, 66.4%, 79.6%**	-, 10.4%, -	2.6%, 11.0%, -	3.1%, 8.9%, -
NLCD Grasses and Shrubs (50s & 70s)		-, 0.1%, -	-, 1.1%, 2.6%	-, 5.8%, 4.8%	**-, 74.7%, 91.1%**	-, 17.3%, 0.5%	-, 0.5%, 0.8%

Table 6-2. Percent classified and percent correctly classified (bold) for NLCD Level Two.

NLCD Class	NAPP Water, 11	NAPP Low-density Residential, 21	NAPP Commercial, Industrial, Transportation, 23	NAPP Bare Rock or Soil, 31	Transitional, 33	NAPP Deciduous Forest, 41	NAPP Evergreen Forest, 42	NAPP Mixed Forest, 43	NAPP Shrub-land, 51
Water, 11	**96.9%, 80.2%, 71.8%**	-, -, 1.0%	-, 1.0%, 2.1%	-, 1.9%, 3.1%	1.0%, -, -	-, 1.4%, 3.2%	1.0%, 1.0%, 1.0%		-, -, 1.0%
Deciduous Forest, 41	0.3%, -, -	0.4%, -, 3.4%			7.6%, 1.4%, 3.6%	**63.8%, 33.2%, 18.4%**	-, 14.3%, 15.0%	19.4%, 6.0%, 16.8%	-, 5.6%, 35.2%
Evergreen Forest, 42	-, -, -	0.1%, 0.1%, 1.1%	1.1%, -, -	1.1%, -, 3.0%	0.1%, 2.0%, -	1.1%, 3.9%, 10.4%	**55.5%, 57.6%, 51.3%**	31.0%, 13.5%, 7.8%	-, 6.3%, 23.4%

NLCD Class	NAPP Water, 11	NAPP Low-density Residential, 21	NAPP Commercial, Industrial, Transportation, 23	NAPP Bare Rock or Soil, 31	Transitional, 33	NAPP Deciduous Forest, 41	NAPP Evergreen Forest, 42	NAPP Mixed Forest, 43	NAPP Shrub-land, 51
Mixed Forest, 43	-, 1.0%, -	1.4%, -, -		-, -, 1.2%	4.3%, 2.4%, -	3.3%, 19.5%, 9.6%	0.2%, 34.9%, 22.8%	**85.6%, 20.5%, 43.1%**	-, 6.5%, 13.3%
Woody Wetland, 91	1.6%, -, -			0.9%, -, 9.4%	3.8%, -, -	4.9%, -, 21.9%	3.0%, 1.8%, -	9.9%, 16.3%, -	-, 1.2%, 40.6%

NLCD Class	NAPP Orchards and Vine-yards, 61	Grass-lands, 71	Hay and Pasture, 81	Cropland, 82	Small Grains, 83	Bare Soil, Fallow Land, 84	Urban Grass, 85	Woody Wetland, 91	Emergent Wetland, 92
Water, 11	-, -, 1.0%	-, 2.9%, 3.1%	-, 1.0%, 1.0%	-, -, 5.1%	-, -, 3.1%	-, 1.9%, -	0.2%, -, -	-, 3.9%, -	1.0%, 4.8%, 3.2%
Deciduous Forest, 41		-, 10.2%, 7.5%	1.8%, 15.2%, -	0.9%, -, -		-, 0.8%, -	3.1%, 0.9%, -	1.8%, 10.5%, -	0.9%, 1.8%, -
Evergreen Forest, 42	-, 2.3%, -	-, 4.9%, 3.2%	0.6%, 2.8%, -			-, 2.0%, -	1.1%, -, -	7.5%, 4.6%, -	0.6%, -, -
Mixed Forest, 43	-, -, 1.8%	-, -, 7.2%	2.0%, 2.4%, 1.2%				2.2%, -, -	1.1%, 10.3%, -	-, 2.4%, -
Woody Wetland, 91	-, -, 9.4%	-, 1.8%, 6.2%	1.8%, 1.8%, -	1.9%, -, -			0.9%, -, -	**67.8%, 72.9%, 12.5%**	3.8%, 4.2%, -

Using these tables, a GIS analyst can determine the "user's accuracy" for any desired TES habitat. For example, suppose a parcel of land in Arizona (EPA Region Nine) contained 500 acres of shrubland defined by NLCD. Since 91.1 percent of NLCD shrubland is actually shrubland, the analyst can estimate that 456 acres of shrubland actually exist for the purpose of measuring "shrub cover and nectar corridors." TES habitat classes with multiple classes must account for the misclassified grid cells being a class still desired by the TES habitat model. For example, mixed forest (43), woody wetland (91), and evergreen forest (42) define "large tracts of mixed deciduous and coniferous tree cover." Any mixed forest cell in Texas (EPA Region Six) has a 20.5 percent chance of actually being mixed forest. But, that mixed forest cell also has a 34.9 percent chance of being evergreen forest and a 10.3 prcent chance of being woody wetland. Thus, that mixed forest cell has a

$$20.5\% + 34.9\% + 10.3\% = 65.7\%$$

chance of being potential habitat for GCW if the other GCW constraints are met. Following are the user's accuracy values for the various TES habitat for EPA regions Four, Six, and Nine:

USER ACCURACY VALUES for NLCD classes in EPA Regions Four, Six, and Nine:

Open water (11)

For gray bat and Indiana bat: 96.9%, 80.2%, & 71.8%.

Deciduous forest (41)

For gray bat and Indiana bat: 85.0%, 64.0%, & 50.2%.

For black-capped vireo: 63.8%, 33.2%, & 18.4%.

Evergreen forest (42)

For golden-cheeked warbler: 94.0%, 78.6%, & 59.1%.

For gray bat and Indiana bat: 95.1%, 79.6%, & 69.5%.

For gopher tortoise and red-cockaded woodpecker: 55.5%, 57.6%, & 51.3%.

Mixed forest (43)

For golden-cheeked warbler: 86.9%, 65.7%, & 65.9%.

For gray bat and Indiana bat: 90.2%, 85.2%, & 75.5%.

Woody wetland (91)

For gray bat and Indiana bat: 85.6%, 91.0%, & 34.4%.

For golden-cheeked warbler: 80.7%, 91.0%, & 12.5%.

Grasses and Shrubs (50s and 70s)

For lesser long-nosed bat: 74.7%, 91.1%.

Only “fragmented places” does not have a precise definition of data quality. Based on the foods brown-headed cowbird eats, fragmented places should be all grasses and shrubs (50s and 70s) cells adjacent to forest (40s) or woody wetlands (91). Without a spatial data uncertainty model performed on specific data layers, it is impossible to determine how useful NLCD data is for representing the quality of areas determined to be “fragmented places.” See Ehlschlaeger (2000)[81] for how complex a spatial data uncertainty model can be.

MODIS

Notes for all MODIS Products

MODIS data provide scientifically measured products available on a regular time scale. Reports from MODIS researchers indicate that MODIS products are constantly changing and improving. MODIS researchers have announced initiatives

81 Ehlschlaeger, C.R. (2000). "Representing Uncertainty of Area Class Maps with a Correlated Inter-Map Cell Swapping Heuristic," *Computers, Environment, and Urban Systems*. Vol. 24, No 5, pp 451-69. URL: http://faculty.wiu.edu/CR-Ehlschlaeger2/older/urban/urban.html.

and upgrades that will improve every data set discussed in this chapter. The biggest issue with MODIS data is the large cell resolution relative to other remotely sensed products. For modeling TES, there are both disadvantages and advantages to MODIS large cell resolution. The biggest disadvantage with 250+ meter grid cells is that some large-scale habitat effects may not be measured accurately. Also, MODIS data is provided in nearly square tiles without any attempt to correct boundary problems. Boundaries problems are evident after combining tiles together as seen in Figure 6-2. Notice the sharp horizontal boundary between grasses and bare ground extending dozens of kilometers.

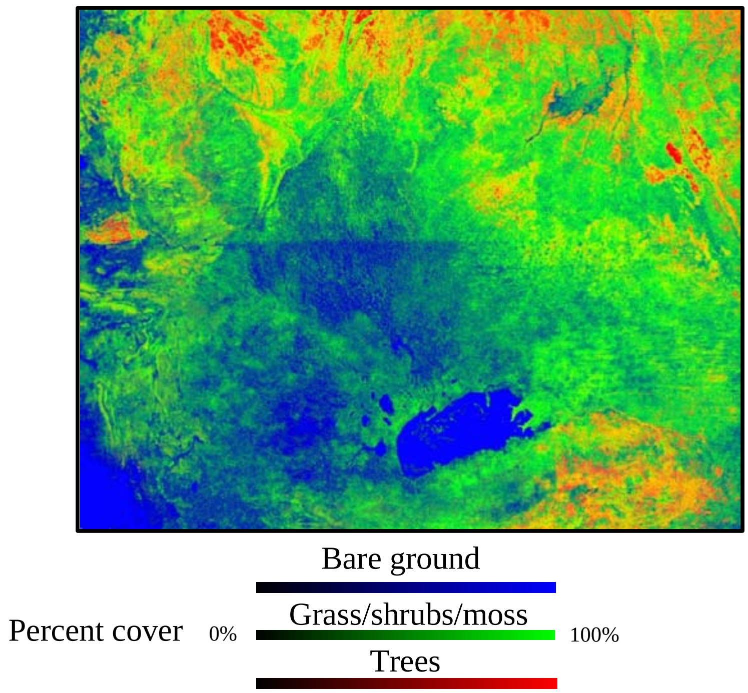

Figure 6-2. MODIS44B composite image from 2000.

The most serious drawback to using MODIS data for monitoring TES habitat change appears to be the uncertain progress of MODIS improvements. Many presenters at the MODIS Vegetation Workshop II in August 2004 were primary researchers in the development of new and improved MODIS products that would fulfill all TES habitat-monitoring needs. However, virtually none of the "coming soon" improvements stated at the conference has been reflected in the official MODIS web site documentation 1 year later. Until these products are delivered and can be independently tested for data quality, it is impossible to be certain of their utility. On a positive note, the main purpose for using MODIS data is for the testing of relative change, for which MODIS products from 2001 and 2002 have demonstrated full capability. Several time series analyses (unpublished, performed by the author of this chapter) on MODIS products (e.g., Leaf Area Index) have demonstrated that these MODIS products are capable of indicating when TES habitat conditions are degrading or improving. However, it would be impossible, using MODIS data alone, to declare whether an environmental emergency is occurring. In fact, if change conditions are noticed using the forest change monitoring MODIS44A product, the supporting documentation states higher quality data should then be used to determine whether the changes exist or are significant.

Notes for each particular MODIS product useful in TES monitoring

The MODIS naming convention is rather complex but it is useful to be able to understand the product codes while reading this section. Here is sample name:

MOD09A1	MODIS/	Terra	Surface Reflectance	8-Day	L3	Global	500m	ISIN Grid
A	B	C	D	E	F	G	H	I

Key to deciphering Product Code:

A: Short Name
B: Instrument
C: Platform
D: Parameter
E: Temporal Resolution
F: Processing Level
  L1: Product accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program effort.
  L2: Product accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts.
  L3: Product accuracy has been assessed and the uncertainties in the product well established via independent measurements in a systematic and statistically robust way representing global conditions.
G: Global or Swath
H: Spatial Resolution
I: Grid or not.

MODIS Quarterly Land Cover Map (MOD44A, Level 3 96-day land cover/dynamics)

MOD44A quarterly land cover data layers will eventually model (for these TES):

- recent land use change occurs (golden-cheeked warbler, gopher tortoise, lesser long-nosed bat, brown-headed cowbird),
- recent urbanization (red-cockaded woodpecker, black-capped vireo),
- recent urbanization and orchard growth (many TES),
- protective canopy flight corridors (gray bat, Indiana bat).

- when MODIS has been around for 20+ years, it can be used to measure tree stand age (red-cockaded woodpecker).

Early validation work[82] with available data sets and Landsat-7 ETM+ data suggests a good relationship between areas identified as change and actual change. Complete validation is currently underway. However, the products mentioned above are not currently ready for release. No definitive date has been offered. Land cover must be validated before MOD44A is useful. Mark Friedl, John Hodges, and Alan Strahler of Boston University are the principal investigators for land cover. They report that land cover has been validated to stage 1. Individual classes have an accuracy of 60 to 90 percent. These estimates are supported by quantitative analysis of unseen training sites, and confidence values aggregated by land cover class. They used field surveys, airborne imagery, and high-resolution satellite imagery for primary reference data.[83]

MODIS Leaf Area Index (MOD15A2)

MOD15A2 can locate places with too little undergrowth (black-capped vireo). Several time-series analyses have been performed (unpublished, by the chapter author) on MODIS products such as Leaf Area Index. MOD15A2 is capable of indicating when TES habitat conditions are degrading or improving. MOD15A2 comes every 8 days but a single 8-day period can mislead TES habitat monitors. TES habitat monitors should compare MOD15A2 8-day maps against MOD15A2 time series from previous years to spot trends and deviations.

MODIS Vegetation Continuous Field Maps (MOD44B, 500-m current, 250-m resolution with collection 5 data)

MOD44B will include percent grasses and shrubs, as well as percent trees to determine prime habitat. MOD44B was scheduled to be released in “mid 2005.” MOD44B will model (for these TES):

- canopy cover (gray bat, Indiana bat),
- sunny grassy areas (gopher tortoise),
- noncontinuous canopies (red-cockaded woodpecker),

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82 From the official web site for MOD44A: http://glcf.umiacs.umd.edu/data/modis/vcc/description.shtml.

83 Information from “MODIS land team validation” by Jeff Morisette, presented at MODIS Vegetation Workshop II, August 2004, Missoula, MT.

- areas with enough grasses and shrubs for Palmer's agave, and enough bare ground to prevent fires from getting too hot (lesser long-nosed bat),
- rangeland clearing for a drop in forest cover (brown-headed cowbird),
- overbrowsing of nearby rangeland by a drop in grass cover with increased bare ground (black-capped vireo).

John Townshend, Ruth DeFries, and Matt Hansen of the University of Maryland are the principal investigators for MOD44B. They report[84] that a procedure currently exists for validation of the MOD44B product. It is true that MOD44B validation can improve, but at large financial or time costs. Results of validation indicate higher accuracy in areas of extreme low or high percentage cover. MOD44B has been validated to stage 1. Product accuracy has been estimated from training data and limited in-situ field validation data sets. Overall accuracy yielded a standard error estimate of 11.5 percent from two field test areas. Field surveys use airborne, IKONOS, and ETM+ imagery.

MODIS MOD14 8-day L3 Fire Product

The MOD14 8-day L3 fire product can be used to locate (for these TES):

- current fires (golden-cheeked warbler, gopher tortoise, lesser long-nosed bat, red-cockaded woodpecker, black-capped vireo),
- potential fire hazard (lesser long-nosed bat).

If MOD14 data isn't required in a GIS; two web sites can provide a graphic representation of current and potential fires for TES habitat monitoring.

http://activefiremaps.fs.fed.us/ is a web site showing "large incidents" of fires in the United States.

http://firemapper.sc.egov.usda.gov/recent3.php shows potential fire danger across the United States.

If MOD14 declares grid cells to have fire, it is very likely there is a fire. However, MOD14 misses late afternoon, cloud-covered fires, and most fires smaller than $100m^2$.

[84] Information from "MODIS land team validation" by Jeff Morisette, presented at MODIS Vegetation Workshop II, August 2004, Missoula, MT.

MODIS MOD14 500-m 32-day burned area product

The 32-day burned area product will provide a more accurate history of burned area (golden-cheeked warbler, gopher tortoise, lesser long-nosed bat, red-cockaded woodpecker, black-capped vireo).

The 32-day product was originally scheduled to be released in the spring of 2005. (This estimate is based on presentations at the MODIS Vegetation Workshop II, August 2004.) Ideally, this data product will be able to identify some fires missed by the 8-day product.

MODIS LST (MOD11) Product

MOD11 can potentially monitor surface soil moisture. More validation of MOD11 is necessary before this surface soil moisture data is useful. MOD11 can be used to model (for these TES):

- moist soil to ensure adequate water supplies (golden-cheeked warbler),
- potential fire hazard (lesser long-nosed bat).

If there is no need to get the data into a GIS, the following web site provides a quick method to see potential fire danger across the United States:
http://firemapper.sc.egov.usda.gov/recent3.php

While MODIS researchers argue that MOD11 can eventually provide an estimate of soil moisture, the actual implementation has not yet occurred.

Potential evapotranspiration (PET) can be calculated as a function of temperature, day length, net radiation (from MOD11), wind speed, and relative humidity. Once PET is estimated, actual evapotranspiration can be estimated as a function of PET and plant and soil properties.

Accuracy of surface temperature is better than 1°K when compared to Heimann thermometers and thermistors, TIR radiometers, and high-resolution imagery. Accuracy is better than 0.5°K in most cases.

FSCPP County Level Population Growth Estimates

The Federal State Cooperative Program for Population Projections (FSCPP) is used to determine population density for various locations (using NLCD as a model of land cover type). As population density increases, use population change to model habitat loss (applicable to golden-cheeked warbler, gopher tortoise, black-capped vireo).

Human encroachment will have a major impact on TES habitat through both direct loss and fragmentation of habitat. Encroachment will occur wherever population growth occurs. The U.S. Census Bureau has a population growth model developed to the county level using the following variables: age, sex, race, and Hispanic origin. State agencies may produce county level projections that include additional variables such as household composition and economic conditions. Understanding where population may grow is critical to monitoring the quality of TES habitat and its fragmentation.

The U.S. Census Bureau has a working relationship with the FSCPP. The FSCPP has state-by-state agencies that distribute the data as well as advise the U.S. Census Bureau on future needs of demographic data and demographic projections. The contact information for the various state agencies is at: http://www.census.gov/population/www/fscpp/contacts.html

Since each state can potentially have a different model for determining population growth, and these models are continuously changing, it is impossible to judge the quality of the population growth forecasts.

National Elevation Data (NED)

NED, http://ned.usgs.gov/, can be used to model (for these TES):

- Steep canyon slopes (golden-cheeked warbler),
- Sunny areas (gopher tortoise),
- Rough terrain (lesser long-nosed bat, black-capped vireo),
- Flat terrain (black-capped vireo),
- Elevations 900-1,500m (lesser long-nosed bat),
- Flat and rolling hills (golden-cheeked warbler).

NED is a seamless data set composed of 3-arc-second Defense Mapping Agency (DMA) Digital Elevation Data, USGS 30-meter Digital Elevation Data, and the latest 10-m horizontal resolution data where available. At this time, only about 75 percent of the United States is covered by the higher quality USGS 30-m data. The NED web site indicates that DEM users should find out what source data was used for a particular region and use the data quality measures for those locations.

TES modelers need to consider both first-order and second-order properties of DEM to determine whether habitat is suitable. Elevation heights (elevations 900 to 1,500 m) are the first order properties, while steep canyon slopes, sunny areas, rough terrain, flat terrain, flat hills, and rolling hills are second order properties.

NED First-Order Data Quality Properties

Data quality research of DMA data in a mountainous region (Ehlschlaeger et al. 1997) indicate that 95 percent of DMA data has a standard deviation of error of 39 m or less when compared to the higher quality USGS 30-m DEM. Since mountainous areas have higher errors overall, we can assume that 95 percent of DMA DEMs are within 117 m of reality. If a TES modeler assumes the 900 to 1,500 m elevation range to be both precise and accurate, s/he should then consider elevations between 883 and 1,617 m to have a 5+ percent chance of being lesser long-nosed bat habitat. Elevations between 1,017 and 1,383 m have a 95+ percent chance of being lesser long-nosed bat habitat.

The USGS portions of NED are supposed to meet the vertical standard: "90% of elevation values shall be within a half contour interval of true values." Unfortunately, USGS DEMs that do not meet that standard are still distributed (and are part of the NED dataset). Also, the control points used to test data quality are more likely to be distributed along roads and urbanized areas. Therefore, the mountainous portions of DEMs, the places with the greatest error, are the least likely to be sampled. If the DEM analyst analyzes each quadrangle's DEM metadata records, s/he can determine what the quality standards should be. USGS DEMs in mountainous areas, if they are meeting standards and have a 50-m contour interval, should have 90 percent of elevation values within 45 m of reality. Thus, lesser long-nosed bat habitat has a 10+ percent chance of being habitat at elevations of 855 to 1,545 m, and a 90+ percent chance of being habitat at elevations of 945 to 1,455 m. If analyzing a region covering many 7.5′ by 7.5′ quadrangles, a modeler could assume a worst-case scenario and treat all the data as DMA quality.

NED Second-Order Data Quality Properties

Identifying rough terrain, flat terrain, sunny areas, flat hills, and rolling hills shouldn't be much of a problem with even the lowest quality NED data, assuming the TES modeler is looking for large parcels of TES habitat. However, identifying steep canyon slopes, for golden-cheeked warbler, can be problematic if the NED source data is DMA 3-arc-second data. DMA DEMs oftentimes will not be able to represent small ridges and valleys in mountainous areas. Valleys must be several hundred meters wide before the DMA DEM will represent them. Even then, slope calculations on these valleys will dramatically underestimate the downhill slope. Since TES modelers will use slope calculations to find steep canyon slopes, they must first identify which portions of the NED are made from DMA data. One rule of thumb for identifying steep canyon slopes would be to assume that slopes on DMA DEMs are 25 to 50 percent greater than the calculations indicate.[85]

U.S. Census Block Population Counts

U.S. Census population enumerations can be used to generate population density maps (for application to golden-cheeked warbler, gopher tortoise, red-cockaded woodpecker, black-capped vireo).

The accuracy of U.S. Census population counts is greater than any TES population model needs. Any errors in representing population density are likely to be corrected by improving the population density model.

Soil Survey Geographic DB (SSURGO)

SSURGO information can be used to identify:

- high surface runoff (golden-cheeked warbler),
- deep, well-drained, sandy substrate at least 1 m above the seasonal water table (gopher tortoise).

SSURGO soil information has long been criticized in the research literature for not being able to provide adequate representations of data quality, especially in areas of soil class boundary representation and not including small polygons of soil classes within large areas. However, without extensive fieldwork, it would be impossible to determine the increase or decrease of potential TES habitat resulting from these errors. Even if a location has a misclassified soil value, the incorrect soil class may also have high surface runoff, if modeling the golden-cheeked warbler. A soil class with the attribute of water table at 2 to 4 m below surface may have large patches with the water table only 0.5 m below surface, harming potential gopher tortoise habitat. Without field checking, TES modelers should assume:

- Up to 30 percent of soils appropriate for potential habitat are really not suitable and
- Up to 30 percent of soils close to but not appropriate for potential habitat are really suitable.

85 Ehlschlaeger, C.R., Shortridge, A.M., & Goodchild, M.F. (1997). Visualizing Spatial Data Uncertainty Using Animation. *Computers in GeoSciences*, Vol. 23(4):387-395.

Of course, digging drainage ditches to drop the water table could easily increase potential gopher tortoise habitat, as this species is already fond of roadside swales. Drainage ditches have the advantage over road swales as potential GT habitat because fewer GT are run over.

TIGER Files

TIGER vector files can be used to locate large bodies of water (important to the gray bat). TIGER files may or may not be necessary for the modeling of large bodies of water. The primary source of water-body information should be the NLCD land cover data. Should significant rivers not be a continuous line of open water as represented by grid cells, the TIGER stream file can then be used to locate the missing grid cells containing the river.

EPA STORET or NWISWeb Water Quality Information

EPA water quality information can be found at:

http://www.epa.gov/storet/about.html

Water quality is useful for modeling gray bat and Indiana bat habitats.

The NWISWeb can be found at:

http://waterdata.usgs.gov/nwis

After a brief exploration of both web sites, the author of this chapter found the EPA's web site more intuitive. However, the EPA's web site is missing data from Texas, Illinois, Alabama, and Mississippi that may be critical for a TES habitat. The author did not find a map of sites on the NWISWeb site.

TES modelers can find water quality information for the locations in Figure 6-3. Biologists would need to consult with hydrologists to determine whether specific streams fit the criteria for quality gray bat and Indiana bat habitat.

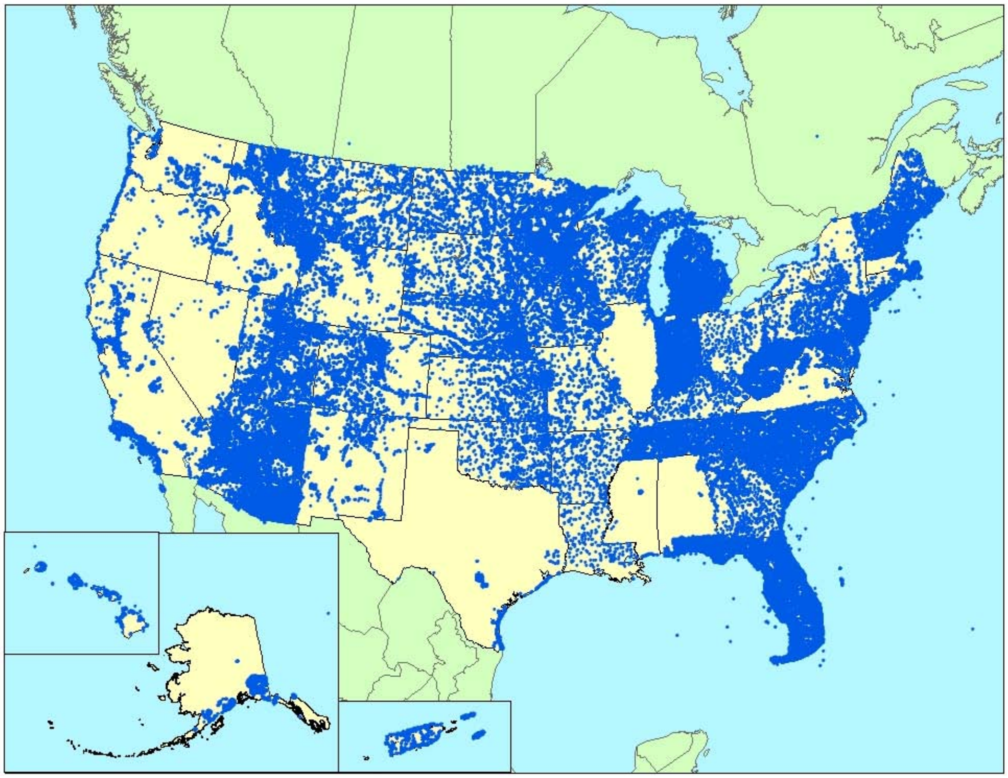

Figure 6-3. EPA STORET sites.

Summary

Data quality impacts the ability to identify as well as monitor TES habitat. Although it may sound too obvious, it must be stated: the data products available for identifying TES habitat cannot guarantee high-quality habitat will exist on parcels of lands not field checked. But, for the purposes of the ACUB initiative, TES habitat modeling will sort parcels into those that require minimal modification to those that require large modification to support TES habitat. In addition, changes in habitat fragmentation can be evaluated from these model results. In this case, if a parcel is not the best for TES habitat, but is critical in preserving a connected (nonfragmented) corridor, then this concern may become paramount over the basic habitat quality. However, the decision to purchase land will require subjective estimate on the potential for long-term human encroachment. For this reason, population growth estimates, road locations, and traffic load patterns will be as or more important than current vegetation cover.

At this time, the delineation of TES habitat is in its infancy. Fieldwork needs to be done to confirm population counts.

7 Data Themes for Monitoring Threatened and Endangered Species Habitat

Dr. Charles Ehlschlaeger

Overview

This chapter was written for installation land managers and developers of GIS databases for the purpose of TES habitat fragmentation monitoring. This chapter provides a list of data products useful to the long-term fragmentation monitoring for Threatened and Endangered Species (TES) habitat. This chapter assumes that the ACUB program has purchased property and/or property rights of TES habitat near military installations using criteria discussed in previous chapters (particularly Chapters 3 and 6) of this document. Since TES habitat is likely to extend beyond the boundaries of military installations and ACUB purchased lands, it will be imperative that DOD land inside installation boundaries, ACUB purchased land, and nearby lands be monitored to ensure TES habitat remains in a nonfragmented state. These lands must be monitored for human development, crop changes, and local climate variations that might temporarily or permanently reduce TES habitat or cause TES habitat fragmentation.

Chapter 3 discussed using data themes to provide an accurate baseline of where quality TES habitat is located. This chapter discusses monitoring previously identified habitat, particularly those patches that have been identified as important habitat corridors for the continued viability of a particular TES. The data themes are listed under Summary of Monitoring Data Themes (page 147) and discussed in detail in the subsequent paragraphs.

Time-series data themes are often too coarse and the data quality is too low to directly measure TES habitat. Instead, the time-series data themes presented here should be used in conjunction with field surveys and the original higher-quality data identifying TES habitat in order to measure the change in quality across habitat areas. Chapter 6 of this report discusses data quality of many of the data themes discussed in Chapter 3 and the present chapter.

Long-Term Monitoring Methodology

Long-term monitoring is probably more "art" than "science." A GIS analyst will have access to map layers that identify quality habitat for each TES, the maps that determined quality habitat location, a map of current land ownership, and monitoring data themes. The analyst would be expected to notice current or future deviations based on monitoring data that would indicate the improvement or degradation of confirmed TES habitat and determine whether remedial action might be required.

Summary of Monitoring Data Themes

This section provides a brief summary of data themes that can be used to monitor the quality of TES habitat. The following monitoring data themes are organized by the extent over which the themes are collected.

Global

MODIS data layers

- Leaf Area Index 8-Day (MOD15A2)
- 8-Day Fire Product (MOD14A2) and/or 32-Day Burned Area Product (not yet available)
- 96-Day Land Cover (MOD44A)
- Surface Soil Moisture (MOD11)
- Vegetation Continuous Field Maps (MOD44B) for
  - percent grass cover,
  - percent bare ground, and
  - percent canopy cover.

U.S. National

- Federal State Cooperative Program for Population Projections (FSCPP) long-term population projections at county level.

Non-Governmental Organizations

- The Nature Conservancy, Ducks Unlimited, etc.
  Ongoing field surveys of TES nests, forage locations, and trails on ACUB lands.

State and Local Governments

- New road construction
- Traffic load on existing highways
- Parcel zoning changes.

Only two of these data sources: MODIS and FSCPP, provide a straightforward data transfer mechanism. As mentioned in Chapter 5, a less standardized format and transfer mechanism increases labor and time commitment, which quickly renders the application of the data too costly to be feasible.

Detailed Description of Monitoring Data

MODIS

MODIS data provide scientifically measured products available on a regular time-scale. The biggest issue with MODIS data is the large cell resolution relative to other remotely sensed products. For modeling TES, there are disadvantages and advantages to MODIS large-cell resolution. The biggest disadvantage with 250+ meter grid cells is that some large-scale habitat effects may not be measured accurately. For this reason, those data themes identified in Chapter 3 provide large-scale detail to identify prime TES habitat. But for monitoring purposes, MODIS data has several advantages over traditional remote sensing data products:

- MODIS, with large-scale auxiliary data, can cover large areas at frequent time intervals. The next best remotely sensed product is Landsat images. Even if Landsat images were free, processing the data would still be costly since it would require 66 times as much disk space, with the corresponding hardware and “wetware” costs.
- MODIS data has already been transformed into useful environmental products. The greatest advantage to MODIS is that it contains so many derived products that remote sensing researchers or technicians are not needed to create products such as continuous vegetation fields, surface moisture, land cover change, and burned area maps.

MODIS data can now be imported easily into GIS data layers using the latest version of many advanced remote sensing software packages (e.g., ENVI, Imagine).

Federal State Cooperative Program for Population Projections (FSCPP)

Human encroachment will occur wherever population growth occurs and this will have a major impact on TES habitat through both direct loss and habitat fragmentation. FSCPP data can be used to continuously monitor encroachment on natural areas of concern for a particular TES. Basically, development will continue to fragment habitats. The contact information for the various state agencies is at: http://www.census.gov/population/www/fscpp/contacts.html.

State and Local Governments

Three available products from state and local governments are useful for monitoring long-term TES habitat: new road construction or expanding road construction, traffic load maps, and zoning parcel changes. Since different states, counties, and cities have different procedures for distributing this data, it will be necessary to contacting each governmental agency to determine their unique transfer procedures. Although data themes from local governments are useful for monitoring TES habitat, they will provide less benefit and require more effort than other data themes. Although available theoretically, in practice the time and cost of acquiring and manipulating these sources tend to prohibit their use. Perhaps as data formats become more standardized this problem will tend to decrease in the (possibly distant) future.

New Road Construction or Expanding Road Construction

New road construction is often the major reason for the initial and continuing development that fragments TES habitat. New roads increase the likelihood that exotic invasive plants will displace native vegetation in the area. New roads also change microclimate conditions that encourage seedier species over shade-tolerant forest species. Proposed new road construction provides an indirect measure of future housing, commercial, or industrial construction. Normally, population growth does not evenly spread away from population centers but rather grows in the direction of infrastructure (particularly road) “improvements.” Should a city plan most of its growth on its section closest to TES habitat areas, encroachment of people, feral cats, pollution, etc. may downgrade the quality of TES habitat.

Due to the importance of (new) roads in contributing to fragmentation, this is one data type for which greater effort to acquire and continually update may be worth the effort.

In Illinois, County Highway Engineers have the latest maps of where proposed highway corridors will be placed as well as final highway layouts. In Kentucky, the 6-year highway construction plans reside at the state level and can be obtained from the Kentucky Transportation Cabinet.

Traffic Load Maps

On existing roads, traffic volume has a relationship with road kill. While most people immediately think of cars striking deer or other big animals, cars and trucks often kill smaller animals and birds. Ongoing and currently unpublished research at Southern Illinois University at Edwardsville, IL, indicates that the relationship is not linear. Road kill has a logarithmic relationship to the car miles per year. In other words, as traffic increases, so does road kill. However, road kill increases more slowly than traffic increases. It is likely that large traffic volumes scare away animals from crowded roads. Therefore, lands near large highways are probably not suitable for TES habitat under any circumstances.

Zoning Parcels

A change in the zoning for parcels in and near cities is another indicator of future population encroachment. In Illinois, cities can declare parcel zoning for all land within 1.5 miles of the city. Figure 7-1 shows Macomb, IL, as the white parcels in the center of the map. Green (agriculture), tan (residential development), blue (industrial development), and red (commercial development) parcels indicate that the city is expecting most of its development to occur east and west of the city proper. (This information is not apparent from the highway maps as highways leave in all four cardinal directions.) It is additionally important that this seemingly sensible policy of cities declaring parcel zoning for all land within 1.5 miles of the city results in effectively claiming an extent of the city a full four times greater than the current area upon which the city resides. Thus it is important to realize that even little urban areas have the potential to significantly contribute to habitat fragmentation with the application of seemingly simple policy.

Unfortunately, TES habitat modelers will have to discover how these maps or data layers are available. In McDonough County, all local governments' maps are free for download from the McDonough County GIS Center. However, different counties have different standards and criteria.

Non-Governmental Organizations

Non-Governmental Organizations (NGOs) will often perform detailed analyses of TES habitat before making purchases of parcels. However, they are leery of sharing their models and data with outside organizations. Based on recent conversations with regional representatives from The Nature Conservancy, they are worried that land values will increase due to speculation if it were known that specific tracts of lands were desirable. NGOs that have already partnered with DoD for TES habitat preservation should be contractually obligated to share survey data with DoD representatives in order for monitoring to proceed. Ideally, both organizations will fully share data themes. Sharing analytical models is probably not feasible.

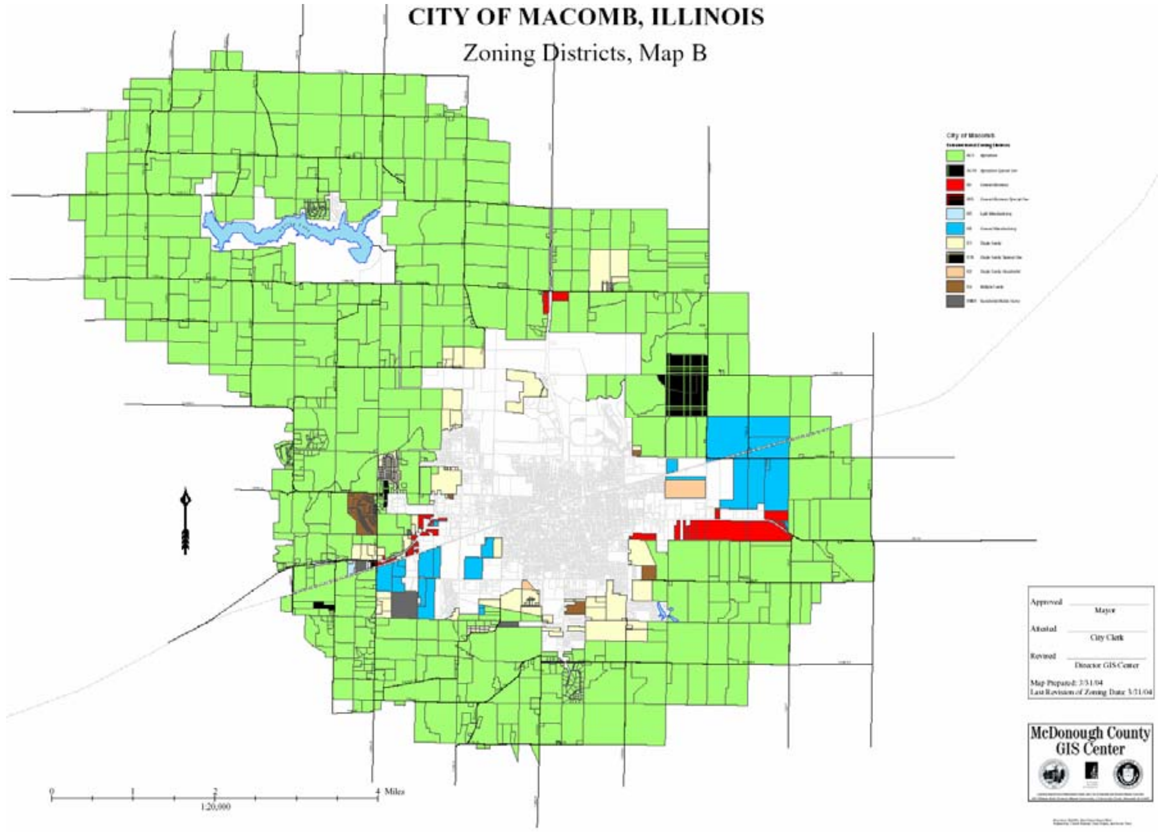

Figure 7-1. Macomb, Illinois, buffer zoning map.

Monitoring Data Themes by Species

The rest of this chapter contains descriptions useful for monitoring TES habitat fragmentation quality. Monitoring data requires a temporal frequency not required for habitat delineation (a single time-horizon occurance). Abbreviated TES life descriptions are available in Chapter 3; more complete descriptions are presented in a related ERDC/CERL Technical Report.[86]

Golden Cheeked Warbler (Dendroica chrysoparia)

- **MODIS 96-Day Land Cover (MOD44A)**. New land cover maps can determine where recent development occurs.
- **FSCPP county level population growth estimates** to estimate future human encroachment.

86 Balbach, H.E. *Profiles for High-Priority Species* ERDC-CERL Technical Report (DRAFT), September 2006.

- The **MODIS LST (MOD11)** product can potentially monitor surface soil moisture. More validation of MOD11 is necessary before this surface soil moisture data is useful.
- The Future **MODIS 500m 32-day burned area** product will provide a more accurate history of burned area. Until available, the **MODIS 8-Day Fire Product (MOD14A2)** is available. However, MOD14A2 is less accurate than the 32-day burned area product will be.
- **MODIS Vegetation Continuous Field Maps** (**MOD44B**, 500-m current, 250-m resolution with collection 5 data) presents percent grasses and shrubs, as well as percent trees to determine prime habitat to ensure enough canopy cover.
- **U.S. Census** block population counts for population density.

Gopher Tortoise (Gopherus polyphemus)

- **MODIS 96-Day Land Cover (MOD44A)**. New landcover maps can determine where recent development occurs.
- **FSCPP county level population growth estimates** to estimate future human encroachment.
- The Future **MODIS 500m 32-day burned area product** will provide a more accurate history of burned area. Until available, the **MODIS 8-Day Fire Product (MOD14A2)** is available. However, MOD14A2 is less accurate than the 32-day burned area product will be.
- **MODIS Vegetation Continuous Field Maps** (**MOD44B**, 500m current, 250m resolution with collection 5 data) presents percent bare ground, percent grasses and shrubs, and percent trees to determine prime habitat to ensure enough sunny, grassy areas.
- **U.S. Census** block population counts for population density.

Gray Bat (Myotis grisescens)

- **MODIS 96-Day Land Cover (MOD44A)** land cover maps can determine where recent development occurs and may signal changes in protective, forested flight routes.
- **MODIS Vegetation Continuous Field Maps** (**MOD44B**, 500m current, 250-m resolution with collection 5 data) present percent bare ground, percent grasses and shrubs, and percent trees to determine prime habitat to ensure forest canopy remains thick.
- **U.S. Census** block population counts for population density.
- **EPA STORET**. Water quality reports for large rivers and lakes.

Indiana Bat (Myotis sodalis)

- **MODIS 96-Day Land Cover (MOD44A)** land cover maps can determine where recent development occurs and may signal changes in protective, forested flight routes.
- **MODIS Vegetation Continuous Field Maps** (**MOD44B**, 500m current, 250-m resolution with collection 5 data) present percent bare ground, percent grasses and shrubs, and percent trees to determine prime habitat to ensure forest canopy remains thick.
- **U.S. Census** block population counts for population density.
- **EPA STORET.** Water quality reports for large rivers and lakes.

Red-Cockaded Woodpecker (Picoides borealis)

- **MODIS 96-Day Land Cover (MOD44A)**. New land cover maps can determine where recent development occurs. After 20-40 years, it would be useful for determining stand age.
- The Future **MODIS 500m 32-day burned area product** will provide a more accurate history of burned area. Until available, the **MODIS 8-Day Fire Product (MOD14A2)** is available. However, MOD14A2 is less accurate than the 32-day burned area product will be.
- **MODIS Vegetation Continuous Field Maps** (**MOD44B**, 500m current, 250m resolution with collection 5 data) present percent bare ground, percent grasses and shrubs, and percent trees to determine prime habitat and ensure forest canopy remains non-continuous.
- **U.S. Census** block population counts for population density.

Black-Capped Vireo (Vireo atricapillus)

- **MODIS 96-Day Land Cover (MOD44A)**. New land cover maps can determine where recent development occurs.
- The Future **MODIS 500m 32-day burned area product** will provide a more accurate history of burned area. Until available, the **MODIS 8-Day Fire Product (MOD14A2)** is available. However, MOD14A2 is less accurate than the 32-day burned area product will be.
- **FSCPP county level population growth estimates** to estimate future human encroachment.
- The **MODIS leaf area index (MOD15A2)** can locate places with too little undergrowth. This would require higher resolution data to define initial conditions.
- **MODIS Vegetation Continuous Field Maps** (**MOD44B,** 500m current, 250m resolution with collection 5 data) present percent bare ground, percent

grasses and shrubs, and percent trees to ensure percent shrub cover remains 17 to 88 percent. **MODIS VCF** can be used to look for rangeland clearing (drop in forest cover which would indicate an increase of cowbirds) or over browsing of nearby rangeland (drop in grass cover with increased bare ground).

- **U.S. Census** block population counts for population density.

Proposing a Long-Term Monitoring Approach

"How does one go about monitoring habitat to identify important changes that may be detrimental to the TES populations?" That is; "How is it possible to ensure that those areas that have been identified as being critical to TES be preserved?" These questions can be more difficult to answer than one may initially suspect because at the landscape scale, installation land managers, and even possibly extra staff from multiple organizations (such as the Fish and Wildlife Service), may not have the manpower to regularly check all those TES habitats. What is needed is a Red Flag Monitoring capability at the landscape scale.

Conceptually, the scheme for providing an alarm or a Red Flag Monitoring capability is easy. Being able to tell what sent the flag up when things change to the detriment of the particular species is also possible. The limiting factor here is the source data in order to feed into such a long term monitoring system.

What are the viable data sources for our Red Flag Early Warning System? We know a few of the qualifications that would be required.

- Clearly compatibility across state and other governmental boundaries.
- A degree of detail (resolution) at a scale compatible with the landscape scale.
- Detail. In some of the research done already (particularly with the Corridor Tool) researchers have come to the consensus that a resolution of 60 meters on an edge is probably more detailed than necessary. The general sense is that a resolution of 120-meter cell size may be equally adequate, at least for purposes of red-cockaded woodpecker monitoring.
- Acquisition of the source data must be inexpensive.
- For data acquisition we need to be concerned with the temporal scale, that is, how often is the data collected and therefore how often can we afford to run our Red Flag System?

Once we put in place this set of criteria our support data sources for the Red Flag System become very limited. It is possible to begin with data sources that do not change overtime. One example is the USGS Digital Elevation Models (DEM) elevation files. Another example comes from the National Biological Survey's (NBS) generalized soil information: Soil Survey Geographic DB (SSURGO). However, if we set up a Red Flag System that uses data that does not change over time, perhaps we have accomplished very little.

If our Red Flag System is to be run once every decade, then there are a few data sources that can support it. Tiger files generated in support of the U.S. Census are a very good example. Another good example generated about once a decade is the National Land Cover Data (NLCD) set. Several derivative data sets can be generated from the NLCD. The most notable of these is the set generated by the U.S. Forest Service that evaluates by various metrics the fragmentation of forests across the United States. But at this point we must also ask the question, "Is once a decade an adequate temporal resolution?" If we wish to be proactive in our management of TES habitat, once every 10 years clearly is not appropriate.

Other agencies have set up data sources that are updated at a frequency greater than once a decade. Notable among them is the EPA STORET system for water quality. Two other data sources can be placed here. The Federal State Cooperative Program for Population Projections (FSCPP) county-level population growth estimate projections come out at irregular but useful intervals. State and county new roads projections both are important indicators of human urban development. The problems with all of the sources in this category are that they come from somewhat dispersed sources, at irregular intervals, and at various levels of quality and detail. At best, these sources would provide a long-term monitoring capability with a temporal repeat frequency of no greater than 3- to 5-year intervals. A habitat could be completely removed from the landscape within a matter of months; none of these data sources will yet provide the land manager with a Red Flag System that can respond quickly to potential detrimental changes to significant to TES.

Now we come to those areas that are more dynamic in the frequency with which data can be acquired. At this point all of them relate to land sensing satellite systems. The best known is Landsat Thematic Mapper (TM). Imagery from it can be used to regularly monitor a region and image processing techniques can be used to generate near real-time information about land cover changes. Although the TM instrument can overcome the frequency and resolution issues it introduces a problem of high cost. Even to the government, each TM image costs at least $400. If we multiply this by about a dozen images to cover a region at a frequency of two times per month, the cost of monitoring becomes great, although not prohibitive.

Although designed for the purposes of tracking climatic change, the Earth Observations System (ESO) carries a small set of instruments that are useful to the monitoring of land surface changes. Probably the most useful instrument for the purposes of regional scale land use monitoring is the MODIS instrument. The advantage of the MODIS program is that NASA generates second- and third-order products from the raw images and these are made available along with the original imagery. At a resolution ranging from 250 meters to 1 kilometer per pixel, the MODIS instrument data products are approximately the correct level for monitoring landscape scale concerns. As the science advances and new MODIS products are validated and generated, they are made available via the Internet. This chapter shows that products of the MODIS instrument are currently a unique source for data required for the Red Flag System. The MODIS instruments (there are actually two currently, one on the Terra platform and a second on the Aqua satellite) cover the entire earth four times a day. NASA generates a set of composite products at a frequency depending on the product (usually once every 8 to 90 days). Those of the greatest interest to us for TES fragmentation monitoring purposes include the Vegetation Indices, the Leaf Area Index, and the Fire products. In many ecosystems the regular occurrence of controlled burns is important because a burn resets the succession of the ecological community. The fact that we now have regular information about land character is a great boon to monitoring ecoregional health. Most significantly, the products are available via the Internet shortly after the images are acquired or within a few hours of when a land composite is generated. And probably just as significantly, these products can be acquired at no cost. At least as an initial set of data sources for the purpose of ecological monitoring at the landscape scale, MODIS data are available.

Remember that for a monitoring capability, we do not require the detail of input data or output results that one requires for habitat fragmentation delineation. In this chapter we have assumed that the habitat has already been defined and field confirmed. Rather, for the purposes of a Red Flag System we need only determine if there is a change in any parameter that is significant to the TES in question.

Although the data sources and expertise exist to generate a Red Flag System to warn land managers if critical areas near their installation are in danger of changing, *no such red flag system exists*. The development of such a prototype would be straightforward. Therefore it is recommended that a prototype TES Red Flag Monitoring System be implemented (Figure 7-2).

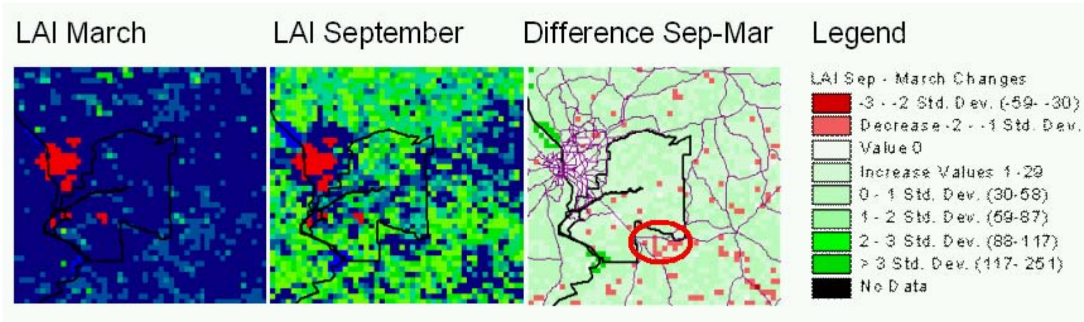

Figure 7-2. Near Fort Benning the difference in MODIS Product Leaf Area Index (LAI) between Spring and Fall show large negative changes.

Roads are overlaid in the right panel to show their coincidence with the very negative LAI changes at the lower right. This Red Flag is an example of the detection of road construction – a major contributor to habitat fragmentation. A military trainer might also be interested in knowing what is causing the large decrease in LAI directly to the south of Fort Benning (the red-circled area) and will that causative agent have an encroachment effect on the training mission assigned to the nearby Training Compartments G and H? Early "Red Flagging" of either fragmentation concerns or potential issues to the military training mission and other responsibilities can help avoid a situation growing significantly worse.

8 The Way Forward

Robert Lozar

Conclusions and Recommendations

From the Summary section of each chapter a few major concerns have emerged from this review of the issues of TES habitat fragmentation as they concern the Army military mission. They lead to the following set of conclusions and recommendations:

1. In the continental United States, as habitat decreases, fragmentation and the constituent TES increase at a rate at least as rapid as the habitat destruction in locations that are better-known to the public. This directly affects military installations land management responsibilities.
2. Habitat fragmentation can only be studied as a species-specific phenomenon. To understand fragmentation, one must look at a landscape through the eyes of a single species. Looking at the same landscape through the life history of another species can yield a completely different level and distribution of fragmentation.
3. Although we have focused in the past on individual species through the Endangered Species Act, the literature shows that single-species management is not always beneficial to the related ecosystems. The cost-effective way to deal with habitat fragmentation is by looking at land at the regional or landscape scale as a single functioning unit.
4. The theoretical basis for dealing with issues at the landscape scale has been developed in the academic field of Landscape Ecology. GIS technology and image processing capabilities are available to address TES habitat fragmentation issues.
5. The isolation that military installations enjoyed in the past is over. Problems dealing with issues of urban development near the military missions have already developed.
6. Installations have become refugees for TES. Those areas outside the installation, which have the potential of providing habitat and therefore taking some of the TES management load off of the installation, are decreasing.
7. Congress has provided some opportunities to help support the preservation of critical TES lands off installation. Using this authority, the Army has created the ACUB initiative. States and environmental organizations can combine funding

with military installations to ensure the conservation of critical TES lands off installations, which have the potential to take some of the TES management load off of the installations.

8. TES do not respect political boundaries and many of them use areas of other countries as part of their regular lifecycle (notably the migration of bats to Mexico). No matter how much the military does, it cannot alone succeed in national management efforts without the cooperation of other bodies. Therefore increased cooperation between these other governmental agencies must be supported at all levels of government.
9. Roughly half of the Army's top seven TES are nocturnal species. An initial review of the literature shows that little attention has been paid to the effect of night lighting on the issues of TES habitat fragmentation. It is feasible that night lighting may fragment nocturnal habitat as severely as cutting down a forest fragments habitat for sylvan species. It is recommended that much more research be done to define the affects of night lighting on nocturnal species habitat fragmentation.
10. It is recommended that a prototype TES Red Flag System be generated, based on the best data sources at the landscape scale.
11. There are a number of fragmentation evaluation programs and models available currently. Although they present different approaches, all of them also fundamentally rely on some version of standard landscape metrics originally pioneered in a program called FragStats. Since this set of landscape metrics provides the core for most programs, they then must be considered as the basis for the direction toward which future research must be aimed.
12. Although several TES habitat and population viability models are available, all of them suffer from the inability to get all required support data. Field research needs to provide better data to management-oriented decision support models and tools.
13. Recommend that the Army sponsor a conference of TES biologist and modelers. The purpose would be to coordinate the two groups efforts. Desired results of the conference would be:
    a. Biologists would agree among themselves what are the basic critical characteristics for each TES habitat for describing viable habitats. These will be required to be in a format that can be measured in the field and successfully summarized as critical TES parameters.
    b. Modelers would agree among themselves what are the basic critical inputs (that can be field measured or derived) they must have to successfully operate their models.
    c. Both groups would agree on those critical parameters that each could viably discuss with the other group. This result should set the direction for coordinated initial research.

d. Both groups would identify those critical parameters that are required but are not liable for field measurement and verification at this time. This result should set the direction for coordinated long-term research.

Appendix: Additional References

Prologue

To provide additional resources for the readers, this bibliography has been developed to amplify those subjects covered directly within each chapter. They are presented in order of the chapters in this guide. Though not necessarily directly related to the specific items discussed in the main text, this appendix is designed to provide a source for further investigation by the reader on specific matters covered. This appendix is presented as additional references roughly related to the different chapter headings. For brevity a reference is presented only once although most of them could rightfully be placed in several sections.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY) 12-2006	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)**
4. TITLE AND SUBTITLE Habitat Fragmentation Handbook for Installation Planners: Status and Options		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Charles Ehlschlaeger, James Westervelt, Harold Balbach, H. Resit Akcakaya, Tom Hoctor, Crystal Goodison, William W. Hargrove, Forrest M. Hoffman, Winifred Rose,and Robert Lozar		**5d. PROJECT NUMBER** 622720A896
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER CNN-T602FF
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) PO Box 9005 Champaign, IL 61826-9005		**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/CERL TR-06-36
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Corps of Engineers 441 "G" Street NW Washington, DC 20314-1000		**10. SPONSOR/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

14. ABSTRACT

The primary objective of this work is to provide military installation planners with a sourcebook on the state of the art in how to analyze the probability and risks of habitat fragmentation for animal Threatened and Endangered Species (TES). The document provides a review of habitat fragmentation issues, focusing on those of highest concern to Army Military Installation Land Managers. It has been designed to capture information developed in during the 4-year ERDC research project called: Quantify Effects of Fragmentation and Approaches to Mitigate. Major components include:

- TES habitat background survey
- Army TES Life histories and potential supporting data types
- Description of major Fragmentation initiatives
- Survey of the major Fragmentation modeling techniques
- Evaluation of Data Quality
- Potential inputs for a long term TES monitoring capability
- Recommendations for future directions.

15. SUBJECT TERMS

environmental management	habitat	threatened and endangered species
encroachment	urban growth	land management

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** James Westervelt
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	SAR	200	**19b. TELEPHONE NUMBER (include area code)** (217) 373-4530