Crime Mapping and Spatial Analysis in National Forests

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ABSTRACT

We examined the spatial distribution of crime incidents on USDA Forest Service lands using a geographic information system and several spatial analysis techniques. Our primary objective was to examine whether patterns existed in the spatial distribution of crime and to explore the relationship of patterns to other geographic features using the Forest Service and other databases. We analyzed a database containing over 45,000 spatially referenced crimes such as felonies, infractions, and misdemeanors. Other spatial data layers included transportation networks, administrative boundaries, hydrology, elevation, and digital orthophotographs. Results at a regional scale showed crime densities concentrated in forests adjacent to population centers and transportation corridors. Nearest neighbor, quartic kernel density estimation, and quadrat analyses identified crime patterning and hot spots. Our results suggest that managers can use these spatial techniques as decision support tools to better understand the relationship between natural resources and crime.

Keywords: GIS, geostatistics

Crime mapping has occurred for over 100 years but it is only recently that geographic information systems (GIS) have begun to emerge as a standard tool for mapping and analyzing crime occurrence (Harries 1999). Initially, GIS was used primarily as a means of producing digital pin maps and evidence suggests that this remains the most prevalent GIS application for crime analysis (Mamalian and LaVigne 1999). Typically, manual pin maps were affixed to the walls of enforcement agencies and discrete locations of crime were indicated with differently colored pushpins to denote crime categories or intensities.

One of the strengths of the GIS is its ability to integrate data from a variety of sources such that social and environmental phenomena can be simultaneously analyzed (Wing and Johnson 2001). A wide variety of digital tools are now available to collect and feed data into a GIS database (Wing and Kellogg 2004). In crime research, GIS has begun to provide pathways to more advanced analytical techniques such as geographic profiling, crime forecasting/prediction, spatial displacement of offenders, hot spot analysis, and exploratory data analysis for examining and mitigating crime (Harries 1999, Anselin et al. 2000, Eck et al. 2000). The application of GIS in crime research still is in its infancy, however, and analytical techniques are being developed and refined.

Successful GIS products involve having the time necessary to collect data and ensure that data are reliable for analysis (Wing and Bettinger 2003). Within the multitude of policing agencies there exists a vast disparity in technological ability (Lersch 2004). Although some advanced agencies make use of automated vehicle location systems and georeferenced computer-assisted dispatching systems, many others use older systems with limited implementation of advanced analytical capability. In some remote and rural areas, limited (if any) computerized recordkeeping is used. Although some agencies require little effort to move their data into information management systems (and may even have limited analytical ability in their production systems), other agencies expend tremendous effort in digital database creation. Some agencies such as the USDA Forest Service still rely on manual entry from paper records.

Technological advancements compel agencies to address resource management challenges more efficiently. Aging infrastructure is being supplanted as many organizations move toward a digitally based incident reporting system. Modern systems are designed to capture location information with greater precision and to rely less on proprietary data storage systems, making their data much more accessible.

National Forest Crime

Research into the nature of crime in national forests is a recent phenomenon. In an illustrative study conducted with Forest Service law enforcement officers (LEO), Chavez and Tynon (2000) uncovered several crime categories: urban-associated crime (e.g., arson, body dumping, domestic violence, drive-by shooting, gang activity, murder, rape and sexual assault, and suicide); assault (e.g., personal assault, criminal property damage, and threats against property); drug activity (e.g., marijuana cultivation, meth labs, meth chemical dumps, and armed defense of crops); and takeover or violence perpetrated by members of extremist and nontraditional groups (e.g., satanic cults, white power groups, EarthFirst!, survivalists, and militia/supremacy groups). The findings were supported by later studies conducted at different Forest Service sites (Chavez et al. 2004, Tynon and Chavez 2006).

Forest Service LEOs face challenges to crime prevention from a variety of fronts.

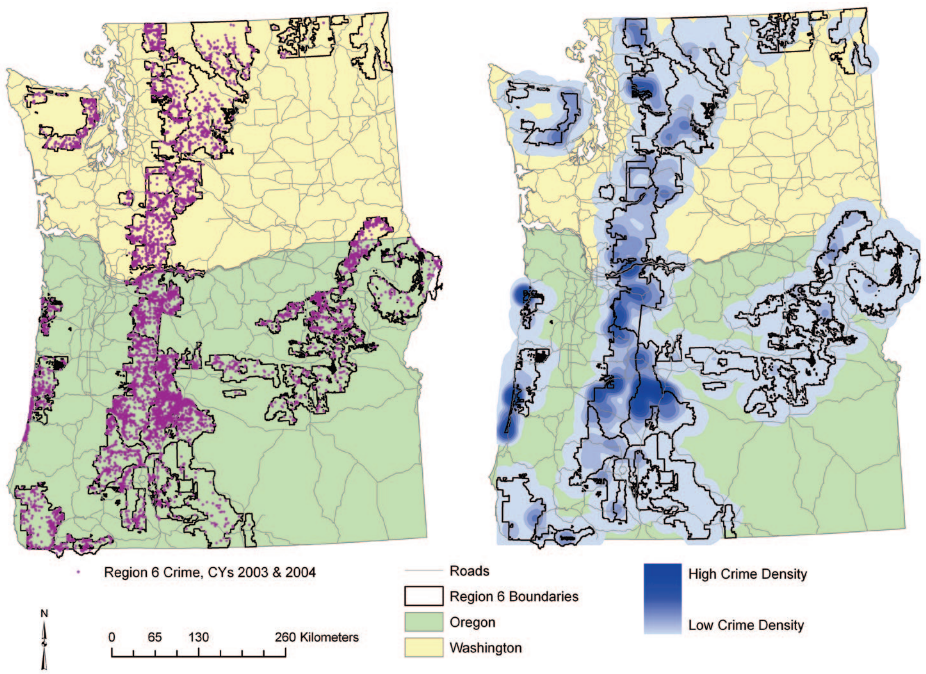

Figure 1. (A) Crime locations and (B) quartic kernel density analysis in Forest Service Region 6.

Many LEOs are geographically isolated, especially in western states where LEOs patrol an average of 378,000 ac alone and backup is routinely an hour or more away (Tynon et al. 2001). LEOs rely on support from county sheriffs' offices, Special Weapons and Tactics teams, drug task force members, and the border patrol. Law enforcement agreements between the Forest Service and other law enforcement entities can result in several agencies tracking crime, potentially creating confusion and inefficiencies. When crime data are collected by non-Forest Service law enforcement, they are not specifically earmarked to national forest lands, they are not included in the Forest Service crime database, and they are not available for analysis. Geographical isolation, understaffed law enforcement, and multiple law enforcement jurisdictions contribute to crime on national forests going unnoticed, being underreported, or reported elsewhere.

The Forest Service created the Law Enforcement and Investigations Attainment Reporting System (LEIMARS) as a digital repository for reporting crime incidents (Tynon and Chavez 2006). LEIMARS contains not only investigative information, but also features the latitude and longitude coordinates of crime incidents, serving as a GIS database. It remains the best and only available source of crime statistics for the entire 781,000 km^2 (193 million ac) of national forests and grasslands in the Forest Service system.

Using GIS as an investigative tool, we conducted spatial analyses of crime incidents on Forest Service lands. Our primary objective was to examine whether patterns existed in the spatial distribution of crime and to explore the relationship of patterns to other landscape features. In addition, we examined how crime violation types were distributed at various administrative levels. Our investigation of national forest crime intensities and crime types provides insight into the magnitude of crime impacts on a regional, forest, and special management unit level. To our knowledge, there are no other published studies using LEIMARS for the spatial analysis of crime in a national forest setting.

Methods

We analyzed Forest Service LEIMARS data for Region 6 incidents reported in calendar years (CYs) 2003 and 2004. The Region 6 database contained over 45,000 spatially referenced crime incidents, covering such crimes as felonies, infractions, and misdemeanors. We obtained the LEIMARS database in a shapefile format and also obtained spatial data layers representing roads, individual national forest boundaries, hydrology, elevation, and color digital orthophotographs of Region 6. We registered all spatial data layers to a common spatial projection to facilitate reliable comparisons between all data layers. We used ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA) and Crimestat (Ned Levine and Associates, Houston, TX and the National Institute for Justice, Washington, DC) spatial software for our processing and analyses. Although the spatial analyses techniques we used were originally developed for urban crime applications, we show they also can be applied in a national forest setting. See Eck et al. (2005) for a description of these and other software packages for analyzing spatial crime data.

In this study we used several techniques to identify crime hot spots. Harries (1999) defines a hot spot as "a condition indicating some form of clustering in a spatial distribution" (p. 112). Others have defined hot spots more specifically but three hot spot criteria generally are acknowledged: frequency, geography, and time. We based our hot spot analysis on the spatial aggregations of crime occurrence over a 2-year period within various administrative and spatial boundaries.

Results

Results are first reported for Forest Service Region 6, which includes all national forests within Washington and Oregon. We then reported results for the Siuslaw National Forest (located within western Oregon), and for a Siuslaw National Forest special management unit, the Oregon Dunes National Recreation Area (ODNRA).

Forest Service Region 6. Forest Service Region 6 consists of approximately 112,396 km^2 (43,396 sq mi) in Washington and Oregon, representing 14.4% of land in the entire Forest Service system. Of the over 45,000 spatially referenced crime incidents linked to Region 6, we located 40,003 crimes within the regional boundary (Figure 1A). The Region 6 map shows the major transportation corridors for the area, the national forest boundaries, and crime event locations. At this small map scale additional map features would not be readily discernible. The middle section of Region 6 runs north to South, roughly along the Cascade mountain range. This area shows a concentration of crime occurrences or crime hot spots, particularly in the area just east of the heavily populated Seattle-Tacoma region of Washington south to central Oregon. Other areas of concentrated crime occurrences are just west of Seattle, along the Columbia River Gorge National Scenic Area, portions of the Oregon coast, and parts of northeastern Oregon. Areas of relatively few crime events are in the northeastern portion of Washington and south central Oregon. These areas also are not in close proximity to major population centers.

Point maps such as the one in Figure 1 are limited because multiple events may be mapped on top of one another. In addition, map scales can confound interpretations because points may not be visible because of clustering. Several spatial analytical techniques are available to assist in the interpretation of crime intensities.

To draw inferences about spatial patterning in Region 6, we conducted a nearest neighbor analysis on the distribution of crime locations. Nearest neighbor analysis describes the distribution of a set of points relative to one another and assumes that points are referenced to a map coordinate system. A nearest neighbor analysis compares an observed set of distances between points with distances that would be drawn from a randomly distributed set of points. Results determine whether observed point distances are systematic, random, or clustered (Krebs 1999). Our results indicated that crimes in Region 6 were significantly clustered (Nearest Neighbor Index [NNI] = 0.21; $P < 0.01$).

Nearest neighbor analysis does not explain where clustering occurs (Chainey and Ratcliffe 2005). Therefore, we ran a quartic kernel density estimation to create a continuous surface representing the density of crimes distributed across Region 6 (Figure 1B). The kernel density estimation illustrates variation in the grouping of crime locations across an area (Chainey et al. 2002). Our kernel density results for Region 6 showed crime hot spots that strongly correspond to those visible in the point location map panel. Although crime hot spots can be inferred through both visual examination of discrete point locations and kernel density estimation, the kernel density approach results in an easier visual identification of hot spots.

Siuslaw National Forest. Quartic kernel density analysis revealed several hot spots in the Siuslaw National Forest, which is near Oregon's Pacific coastline. The Siuslaw National Forest consists of approximately 3,345 km^2 (1,292 sq mi). However, the area for the Siuslaw National Forest minus private inholdings is approximately 2,536 km^2 (979 sq mi). There were 4,763 logged crimes within the Siuslaw National Forest during CYs 2003 and 2004 (Figure 2). This represents 11.9% of all crimes reported in Forest Service Region 6.

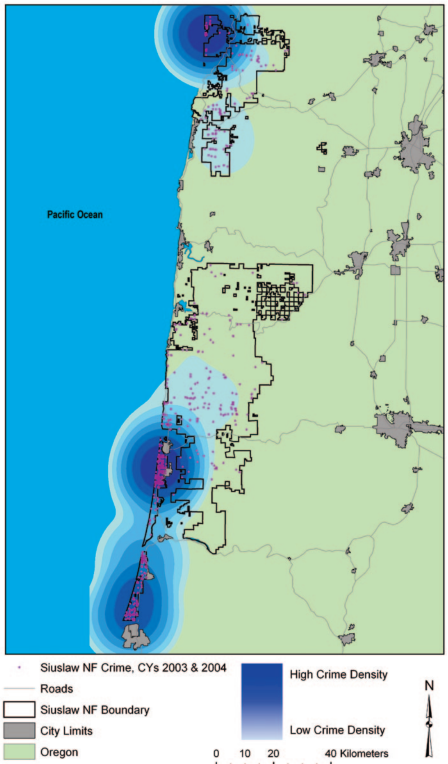

Figure 2. Crime locations including quartic kernel density analysis for the Siuslaw National Forest.

The Siuslaw National Forest map shows the national forest boundary, major transportation corridors, major cities, and crime event locations. Several urban population centers can be seen East of the Siuslaw National Forest, along Interstate highway 5. Crime hot spots appear to be concentrated in those portions of the Siuslaw National Forest that border the southern coastline. This is where ODNRA is located. The ODNRA runs parallel to Oregon's scenic coastal highway, US Route 101.

Our nearest neighbor analysis results indicated that crimes in the Siuslaw National Forest were significantly clustered (NNI = 0.14; $P < 0.01$). Our kernel density estimation identified three distinct crime clusters, with one hot spot in the northern section and two in the ODNRA (Figure 2).

ODNRA. The ODNRA consists of approximately 141 km^2 (54 sq mi). The size estimate for ODNRA minus private inholdings is approximately 125 km^2 (48 sq mi). There were 2,114 logged crimes within the administrative boundaries of the ODNRA (Figure 3). This represents 44.4% of all crimes reported in the Siuslaw National Forest and 5.3% of all crimes in Region 6.

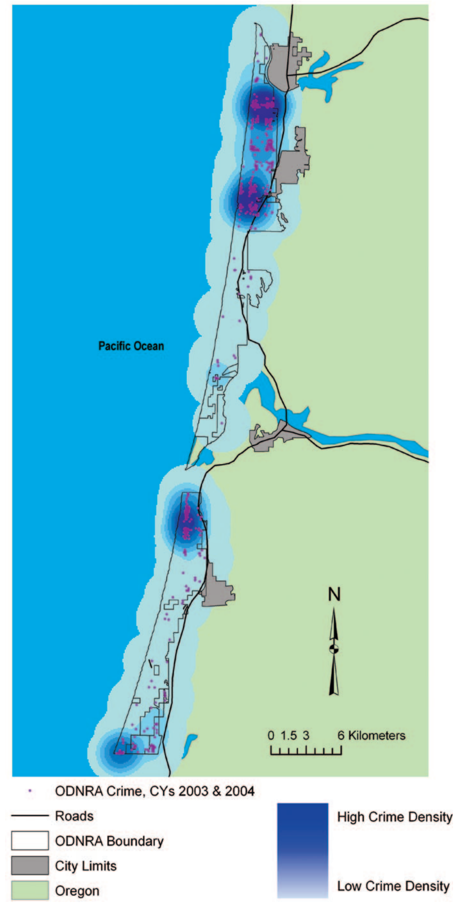

Figure 3. Crime locations including quartic kernel density analysis for the ODNRA.

The ODNRA map shows the administrative boundaries, major transportation corridors, major cities, water bodies, and crime locations (Figure 3). The ODNRA is bound in the north and south by large population centers and flanked on the eastern side by several smaller cities. One crime hot spot is just below the midpoint of the ODNRA, and to a lesser extent, the most southern portion of the ODNRA. Most hot spots appear to be concentrated in the northern portion of the ODNRA, adjacent to two population centers and two popular inland fishing destinations.

Nearest neighbor analysis results indicated that crimes in the ODNRA were significantly clustered (NNI = 0.18; $P < 0.01$). Kernel density estimation identified four distinct crime hot spots, two grouped closely together in the northern portion and two in the southern portion separated by approximately 10 km (Figure 3). The northern hot spots appear to have stronger crime densities.

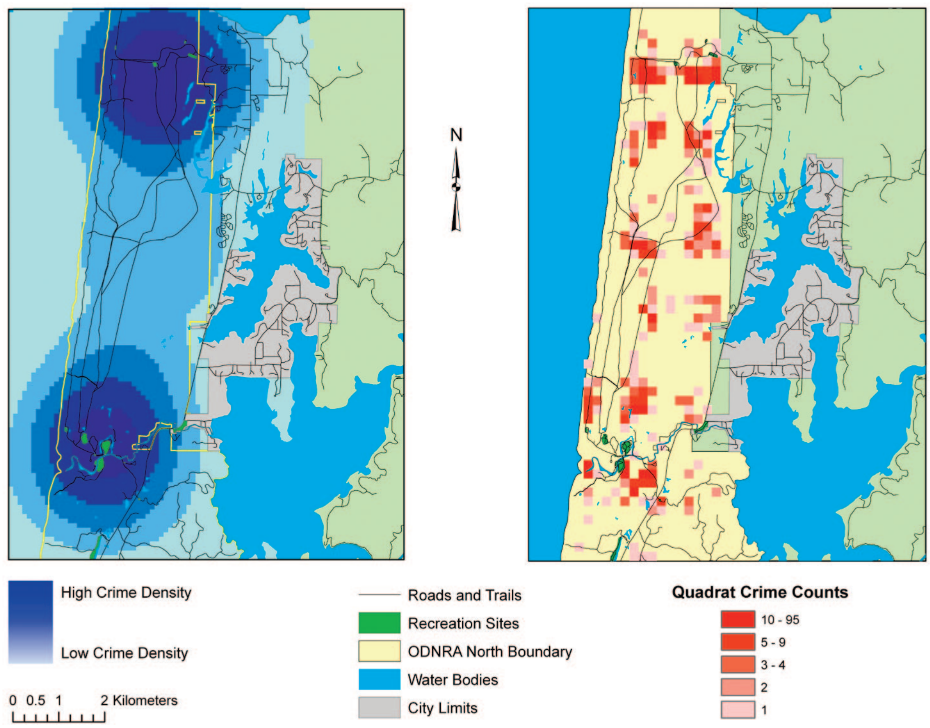

Figure 4. (A) Quartic kernel density analysis and (B) quadrat analysis of crimes in the northern portion of the ODNRA.

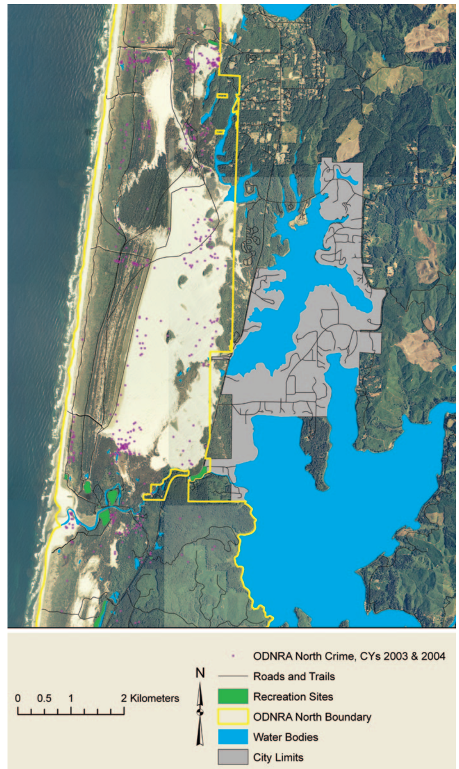

Figure 5. Crime locations and digital orthophotographs for the northern portion of the ODNRA.

ODNRA—North. The map of the northern portion of the ODNRA shows roads and trails, rivers and lakes, city limits, recreation facilities, and crime locations (Figure 4). Kernel density estimation identified crime hot spots primarily in two locations (Figure 4A).

At larger mapping scales such as the one in Figure 4, kernel density estimations can exaggerate the distribution of crime problems. One spatial technique to address this limitation is quadrat analysis. Quadrat analysis divides an area into equally sized grid cells and summarizes the number of crimes that occur in each grid cell (Eck et al. 2005).

We selected a grid cell resolution of 200 m per side for our quadrat analysis (Figure 4B). At this scale, it is clear that using quadrat analysis eliminates the exaggerated overlap seen in kernel density visualizations by grouping crime summaries into smaller spatial units, creating more readily apparent crime hot spots. In addition, the relationship of crime events to other landscape features is discerned more easily.

Our quadrat analysis results show several crime hot spots located along the transportation network and several in proximity to established recreations sites. A linear pattern of crime hot spots is evident in the quadrat analysis results but can not be explained without additional information. We added color digital orthophotograph quadrangles (DOQ) taken in 2003 to complement other ODNRA data layers (Figure 5). The DOQs provide the kind of detail that allows better interpretation of the landscape within the ODNRA and environs. Specifically, this enhanced level of detail moves away from the abstraction of polygons and toward a more realistic manifestation of the resource. Significant features apparent in this layer include off-highway vehicle (OHV) trails, vegetation, forest management activities, built facilities and structures, and sand dunes. Surf conditions are readily discernible.

Zooming in on Hot Spots. Using individual crime locations, we visually identified a number of hot spots in the northern portion of the ODNRA. Landscape phenomena, such as transportation networks, topography, and facilities, offer some explanation for these hot spots. Although many of the hot spots are close to recreation facilities, northern hot spots are in close proximity to roads. In contrast, one hot spot in the southern dune area does not share either of these characteristics. However, closer visual inspection of the DOQ layer revealed an established trail leading into the dune area from the south. We took advantage of a digital elevation model (DEM) to inspect the topography of this dune area. Topographic contours created from the DEM revealed an area of noteworthy relief likely to attract OHV users. Additional investigation of the LEIMARS database revealed that the majority of violations (56.3%) in this hot spot were indeed related to OHV use.

Violation Levels. Violation levels for Region 6 in the LEIMARS database were organized into the following categories: administration, civil, felony, infraction, misdemeanor, noncriminal, and petty offense (Table 1). Examples of administration offenses were cutting or damaging of trees and offenses associated with archaeology resource protection. Civil crimes included property damage, causing a fire, fire negligence, and highway vehicle accidents. Examples of felonies were assaults on LEOs, unlawful acts with firearms, and drugs. Infractions included such things as leaving the scene of a fire, failure to pay recreation fee, off-road vehicle violations, and driving without a license. Examples of misdemeanors were alcohol violations, polluting waterways, timber theft, and criminal mischief. Noncriminal offenses involved search and rescue, accidents, and property damage. Petty offenses included incidents with uncontrolled animals and building a fire.

Table 1. Violation level percentages within three Forest Service administrative units.

Violation level	Region 6	Siuslaw NF	ODNRA
Administrative	0.1% (34)	0.0% (0)	0.0% (0)
Civil	0.1% (27)	0.0% (2)	0.0% (0)
Felony	1.4% (552)	1.0% (49)	0.4% (9)
Infraction	7.6% (3,023)	4.0% (191)	2.6% (55)
Misdemeanor	88.6% (35,462)	91.9% (4,376)	92.1% (1,946)
Noncriminal	2.0% (797)	3.0% (144)	4.9% (103)
Petty offense	0.3% (108))	0.0% (1)	0.0% (1)
	(40,003)	(4,763)	(2,114)

Numbers in parentheses are total counts.

The majority of violations reported in Forest Service Region 6 for CYs 2003 and 2004 were misdemeanors (88.6%), followed by infractions (7.6%), noncriminal offenses (2.0%), and felonies (1.4%). According to the National Visitor Use Monitoring database, the Siuslaw National Forest draws an estimated 1,864,268 visitors per year, or 6.6% of total Region 6 visitors. The majority of violations recorded for the Siuslaw National Forest were misdemeanors (91.9%), followed by infractions (4.0%), noncriminal offenses (3.0%), and felonies (1.0%). The majority of violations recorded for ODNRA were misdemeanors (92.1%), followed by noncriminal offenses (4.9%), infractions (2.6%), and felonies (0.4%).

Discussion

Although GIS applications are ubiquitous in natural resource management, ours is the first published study to use GIS to analyze crime occurrences in national forest settings. Examining the spatial distribution of LEIMARS crime occurrences is an improvement over the one-dimensional manipulation of tabular data. GIS technology allows the visualization of information such that data relationships and correlations with environmental factors can be explored more easily and are less likely to be overlooked.

Our results showed that crime hot spots tend to concentrate in those forests adjacent to population centers and transportation corridors (Figure 1). Three other crime hot spots in the western portion of Region 6 are close to marine destinations. Visual and spatial analysis indicated that the Siuslaw National Forest had a large proportion of hot spots. Our summary statistics of the tabular database revealed that 11.9% of all crimes reported in LEIMARS for Region 6 occurred in the Siuslaw National Forest. This discovery prompted us to inspect the Siuslaw National forest at a larger map scale and, eventually, to identify hot spots within a special management area.

GIS could make important contributions to Forest Service crime management as a decision support tool. For example, by incorporating multiple layers representing other landscape features at a larger map scale, we were able to make visual inferences about crime hot spots. One key management implication is how to best direct crime prevention and mitigation resources. Decision support efforts should include identifying places where crime is prevalent and determining where crime types occur with greatest frequency. GIS and spatial analysis can provide a pathway for managers to better understand the relationship between natural resources and crime occurrence.

The LEIMARS database is the best source for spatially referenced crime information on Forest Service lands. Nevertheless, the LEIMARS database showed 5,721 crime points that were associated with Region 6 but located outside forest boundaries. These outliers represented 12.5% of the total number of crimes in Region 6 during CYs 2003 and 2004. Points outside national forests varied in distance from boundary lines. They ranged from 1 m (3.3 ft) to 115 km (71.5 mi), with an average distance of 5.5 km (3.4 mi) to the nearest national forest boundary. Some of these distance discrepancies can likely be attributed to human error through incorrect data entry or map interpretation. Digital field input using handheld global positioning systems receivers could help alleviate some spatial registration problems, because even a 1° error in entering a latitude coordinate results in an error of approximately 111 km (~69 mi).

Other database entry errors were evident in the LEIMARS database. Some data were entered in the wrong columns, some data were missing, and some data had incorrect numeric references; these problems can hamper database manipulation and analyses. There also was insufficient data to differentiate why similar violation code references were reported at different violation levels. Despite these problems, LEIMARS offers significant potential advantages over nonspatial databases.

An immediate benefit of the spatial component in the LEIMARS database is the ability to use GIS to visually explore spatial distributions of crime hot spots and relationships to other spatial data layers. Spatial analyses approaches such as the nearest neighbor analysis can reveal whether patterning, clustering, or heterogeneous relationships exist. More advanced techniques such as the quartic kernel density and quadrat analyses can reveal information about the spatial intensity of crime. Visual explorations, enhanced by analytical approaches such as nearest neighbor analysis, kernel density estimates, and quadrat analysis can confirm or deny observed patterns. In addition, spatial analysis results can assist in identifying hot spots that should receive increased vigilance or resources. Once hot spots are identified, closer visual examinations can specify areas for enforcement action. Research results from these spatial analyses can be applied to efforts to quantify, analyze, and mitigate crime. Spatial databases that capture, e.g., socioeconomic, demographic, or landscape data, can help identify potential influences on crime variable distributions.

Areas for Future Research. Our preliminary results lead us to ask several questions. Are hot spots really indicating more crime or is there simply more reporting of crime because of easier patrol access? Do fewer points on a map mean fewer patrols or fewer crimes? Perhaps access via transportation corridors or proximity to population centers and recreation facilities leads to increased crime. There also may be potential to identify opportunities for crime concealment facilitated by landscape features such as topography, vegetation, and access points. Managers could use this information in their crime prevention efforts. In addition, the proximity of crime incidents to administration and law enforcement offices remains to be examined.

The Forest Service has been compiling spatial locations of crime through their LEIMARS database for some time but has the opportunity to lead the way in developing a model for the cataloguing and analysis of spatially referenced crime events in natural resource settings. In addition to the hot spot analysis discussed here, future efforts could examine geographic profiling, crime forecasting/prediction, and the spatial displacement of offenders as a means to mitigating crime. Additional areas of investigation might compare Forest Service crime data to crime reported in adjacent, non-Forest Service areas. More sophisticated crime analyses might address causality in relation to environmental factors.

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