EPA 600/A-98/061
2240A

TEXTURE ANALYSIS OF RIPARIAN CONIFEROUS FOREST ADAR IMAGERY TO IDENTIFY POTENTIAL ECOLOGICAL INDICATORS FOR MONITORING*

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PB98-151244

ABSTRACT

The Airborne Data Acquisition and Registration (ADAR) remote sensing system captured one-meter resolution imagery of 25 different riparian sites in Drift Creek Basin of coastal northwestern Oregon, USA. The multispectral, digital data characterized riparian areas with the intent to develop ecological indicators for long-term monitoring. The ADAR images of five sites that varied with respect to riparian forest attributes were subjected to a texture analysis with 96 different variables. This initial screening assessed the effectiveness of the texture variables to characterize different forest canopy attributes such as the ratio of conifer canopy to deciduous canopy. Regression models were developed to predicted canopy attributes from the texture variables. Some canopy attributes that were statistically correlated with the texture variables also provided information on below-canopy attributes such as tree density or basal area that could not be assessed by analysis of the ADAR imagery.

1.0 INTRODUCTION

Aquatic conservation strategies developed for the Pacific Northwest region of the United States through federal and state policy seek to protect and improve riparian areas by new management practices to ensure a sufficient number of trees that provide shade, channel stability and a continuous supply of large woody debris to streams (Lorensen et al., 1994; USDA/FS and DOI/BLM, 1994). Consequently, the extent and condition of riparian forests in the Pacific Northwest is of great interest to land management agencies, forest industries, and conservation groups. This has created an immediate need to characterize the extent and condition of different types of riparian forests, and to identify ecological indicators for long-term monitoring. Given the immediate need for information and the large geographical area of the region, remote sensing is a logical choice for the monitoring program as it provides an efficient and economically viable approach (Hewitt, 1990).

Identification of key ecological indicators is crucial to a riparian monitoring protocol. Ecological indicators are attributes that are measured to provide statistically sound information on the biological condition of the resource (Barber, 1994). For example, riparian forests provide important functions to the aquatic system such as mitigating the input of solar heat, maintaining bank stability, supplying nutrients and large woody debris, and retaining sediments (Gregory et al., 1991). Ideally, ecological indicators should provide data on these functions with a known degree of certainty, and also be unambiguously interpretable, ecologically responsive, and stable with low measurement error. Indicators also need to provide information for sound management action (Reilly, 1989). The information gained from the characterization of riparian attributes in relationship with ecological processes can identify indicators for monitoring needs. Potential indicators examined in this paper include different metrics of canopy cover, tree size composition and density, and average stand height. Knowledge of these riparian attributes could improve stream management.

During past decades, forest inventories were produced mainly from the interpretation of low resolution aerial photography (e.g., 1:24,000) and satellite digital imagery (e.g., 30 m). However, due to the "ribbon-like" nature of riparian zones within the larger forested landscape, high spatial resolution (e.g., 1.0 m) is needed for the fine-featured objects that characterize these ecosystems. Riparian zones are linear, anisotropic, and hierarchically structured with large extent but fine-grained texture.

The Airborne Data Acquisition and Registration (ADAR) system is capable of providing high-resolution imagery. This system was used to acquire one-meter resolution imagery of 25 different riparian sites in Drift Creek Basin of

* Presented at the First International Conference on Geospatial Information in Agriculture and Forestry, Lake Buena Vista, Florida, USA, 1-3 June 1998.

coastal northwestern Oregon, USA. ADAR is a good choice for riparian monitoring because it provides multispectral digital data, its is commercially available, and it provides high resolution imagery that is now becoming popular with new aircraft and satellite mounted sensors (Fritz, 1996). Specific research goals are to (1) evaluate riparian forest attributes that can be distinguished with one-meter resolution digital imagery; (2) identify what type of texture analysis provide this information; and (3) evaluate if texture analysis can indirectly characterize below-canopy attributes. The ADAR imagery of five sites that vary with respect to riparian forest attributes were subjected to texture analysis. Texture analysis is an important technique used in image processing for pattern recognition because it can provide information about the spatial properties of the fundamental units in the image in addition to that provided by classification of the spectral data (He and Wang, 1990; Ryherd and Woodcock, 1996). This initial screening assessed the effectiveness of the texture variables in characterizing different forest-canopy attributes such as the ratio of conifer canopy to deciduous canopy. Canopy attributes that were statistically correlated with the texture variables derived from the ADAR data were then analyzed to see if they could be predictive of below-canopy attributes such as tree density or basal area.

2.0 METHODS

2.1 STUDY AREA, SITE SELECTION, AND FIELD DATA

The geographic location of this study was Drift Creek Basin located in coastal northwest Oregon of the United States (approximately 123° west longitude and 44° north latitude). The basin is about 140 km^2 in area and contains 260 km of streams (Oregon Dept. of Forestry, 1994). Drift Creek Basin contains a variety of forest types ranging from never-logged wilderness areas to young conifer plantations. Dominant trees include Douglas fir (*Pseudotsuga menziesii* (Mierbel) Franco), western redcedar (*Thuja plicata* Donn.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and western red-alder (*Alnus rubra* Bong.).

Twenty-five sites were selected from a stratified probability sample of stream size and forest type. Five sites (Table 1) that represented the range of stand types in Drift Creek Basin were subjectively selected to develop a protocol for the analysis of the remaining data set. A cluster analysis based on the forest stand attributes, and using Euclidean distance provided confirmation for the subjective selection.

Field data were collected during August and September 1996. At each of the sites, a 40x40 m plot was aligned along the edge of the bankful width of the stream to obtain the field measurements of riparian attributes (Table 2). Different riparian forest attributes were measured to provide a "ground truth" for the multispectral imagery. All trees having a diameter at breast height (DBH) greater than 15 cm were inventoried. The DBH and species were recorded for each tree, as well as its location in the plot. Canopy density was measured using a densiometer at 8 locations spaced equal distances throughout the plot. Each observation consisted of an up-slope, down-slope, up-stream, and down-steam reading that were used to calculate percent cover. Canopy diameter for each tree was based on DBH and calculated using allometric equations. Average stand height was determined by measuring the height of 3 to 4 average-sized trees.

Table 1. Distinguishing Features of the Five Riparian Forest Sites

Site	Stand Type	Management	Age	Height, m	Conifer / Total Cover
10	Conifer	Never logged	Mature	57	1.0
16	Mixed	Natural regeneration	Young	30	0.6
19	Conifer	Plantation	Young	29	1.0
21	Conifer	Plantation	Young	22	0.9
23	Deciduous	Never logged	Old	30	0.2

2.2 ADAR IMAGERY

The ADAR System 5500 (Positive Systems, Inc.; www.possys.com) was used to capture the remote sensing imagery at a spatial resolution of one meter. One-meter resolution was selected to enable a consideration of

Table 2. Riparian Forest Attributes

Riparian Forest Attributes	Description
Canopy attributes	
CONCROWN	Conifer crown cover, m^2
DECCROWN	Deciduous crown cover, m^2
TOTCROWN	Total crown cover, m^2
CON/TOT	Conifer cover / total cover
DEC/TOT	Deciduous cover / total cover
DEC/CON	Deciduous cover / conifer cover
DENSITY	Canopy density, %
Below-canopy attributes	
HEIGHT	Average stand height, m
TDEN	Total tree density, number / area
CDEN	Conifer tree density, number / area
DDEN	Deciduous tree density, number / area
DBHS/L	Total small tree DBH / total large tree DBH†
TBA	Total tree basal area , m^2
CBA	Conifer tree basal area, m^2
DBA	Deciduous tree basal area, m^2

† Small trees = DBH $\leq$ 50 cm, large trees = DBH > 50 cm,

the level of resolution that is necessary to describe riparian features. The ADAR sensor provided digital imagery in four color bands: band 1 (blue, 450-520 nm), band 2 (green, 520-600 nm), band 3 (red, 630-690 nm), and band 4(near infrared, 760-900 nm). The sensor had an array of 1000 by 1500 imaging elements that provided an image area of 1.5 ha^2 at one-meter resolution. The ADAR imagery was collected on 9 and 10 September 1996 within two hours of solar noon using a fixed-wing aircraft flying at an altitude of 2333-2697 m. Reasonable adherence to the Draft Aerial Photography Standards were followed with adaptation appropriate for multispectral digital imagery (American Society for Photogrammetry & Remote Sensing, www.asprs.org/asprs/resources/standards/daps.html). Each fight line was upstream with five images collected per site with 60 % endlap. The field plot was centered in image 3. Post flight processing included vignette correction and band to band alignment. The 40x40 m plots were located on image 3 using visual features identified from the field observations and/or GPS data.

2.3 IMAGE PROCESSING AND DATA ANALYSIS

A variance texture algorithm was applied to all four bands of the original (RAW) ADAR data and to three transformed versions of the spectral data using 3x3, 7x7, 11x11, and 15x15 filter sizes. The image transformations included calculation of the normalized difference vegetation index (NDVI = band 4 - band 3 / band 4 + band 3), the first three principle components (PCA) of the four ADAR bands, and applying a 7x7 adaptive (ADP) filter to all four ADAR bands. The ADP enhances contrast locally within the filter window to enhance details in small-scale uniform areas. The mean and standard deviation for each 40x40 m site was extracted from the image variables. ERDAS Imagine software was used to apply the texture algorithm and image transformations (ERDAS, Inc., 1997). In all, each site had 96 different texture variables calculated from the ADAR data. The texture calculations only include pixels within the 40x40 m plots since this area was described in the field reconnaissance. Pearson correlation coefficients were calculated to relate texture variables to canopy attributes. Least-squares regression models were then calculated to predict canopy attributes (dependent variables) that were significantly correlated to texture variables (independent variables). Below-canopy attributes were also statistically analyzed for correlations with the texture variables. In addition, canopy attributes that were highly correlated with a texture filter were then regressed with the below-canopy attributes not directly measured by the ADAR imagery to identify any statistically important relationships.

3.0 RESULTS

The texture variables were evaluated as to their effectiveness in using the canopy attributes to discriminate among the riparian sites. The mean values for all texture variables were plotted against filter size to inspect how well each combination distinguished the five sites. The variable at a particular filter size that separated the sites were selected for statistical analysis. For example in Figure 1, the 3x3, 7x7, and 11x11 windows of the PCA1 standard deviation variable failed to clearly discriminate the five riparian sites, but they were adequately separated with the 15x15 filter. Only data from the 15x15 filter were statistical analyzed.

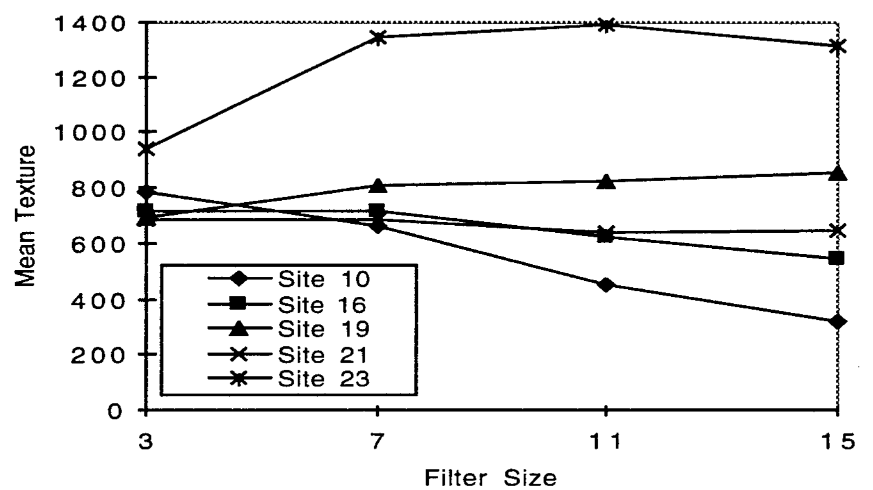

Figure 1. PCA1 standard deviation variable with four filter sizes

Thirty-four different texture variables and filter combinations met the above criteria and were used for Pearson correlation analysis with the canopy attributes (Table 3). CONCROWN correlated with RAW, PCA, and ADP at the smaller-sized filters. DEC/CON correlated with RAW, PCA, and ADP at the larger filter sizes. CON/TOT and DEC/TOT were negatively and positively correlated with the PCA and ADP, respectively.

CONCROWN, DEC/CON, CON/TOT, and DEC/TOT are metrics that describe different compositions of the riparian forest canopy. The regression models revealed that by selection of appropriate texture variables as guided by the Pearson correlation values, statistically significant estimates of these attributes were obtained (Table 4). Each of the canopy attributes were estimated by several different texture variables with a high degree of confidence. Many of the regression equations accounted for greater than 85 % of the modeled variance in predicting the respective canopy attributes.

DBHS/L is not a canopy attribute, but is a simple metric of tree-size diversity in the stand (Table 1). However, it was the only below-canopy attribute that correlated significantly with a texture variable, and was therefore grouped with the canopy attributes. DBHS/L was best estimated from the PCA2 standard deviation and NDVI mean variables, and both texture variables accounted for at least 90% of the modeled variance (Table 4).

Table 3. Significant Pearson Correlations between the Texture Variables and Canopy Attributes

Texture	Canopy Attributes				
Variables	CONCROWN	DEC/CON	CON/TOT	DEC/TOT	DBHS/L
RAW2T3X†	+++*	+	+	+	+
RAW3T3X	+++	+	+	+	+
NDVIT7X	+	+	+	+	+++
PCA1T3X	+++	+	+	+	+
PCA2T15X	+	+	+	+	++
ADP2T7X	+++	+	+	+	+
RAW1T15S	+	+	+	+	+
RAW2T3S	+	++	+	+	+
RAW3T11S	+	+++	+	+	+
RAW3T15S	++	++	+	+	+
NDVIT11S	+	+	+	+	++
PCA1T7S	+	+++	++	++	+
PCA1T15S	++	+	+	+	+
PCA2T15S	+	+	+	+	+++
ADP1T11S	+	+++	++	++	+

† Texture variables: RAW2T3X is defined as RAW= original data, 2 = band 2; T3X = mean for 3x3 filters, T3S = standard deviation for 3x3 filters, PCA1 = first component of the principle component analysis transformation, NDVI = normalized difference vegetation index transformation, ADP = adaptive transformation

* Pearson correlation significance level: + = $p < 0.10$, ++ = $p < 0.05$, +++ = $p < 0.01$

Table 4. Regression Models that Estimate Canopy Attributes from the Texture Variables

Riparian Forest Attributes	Texture Filter with Coefficients	r^2	P	SEE
CONCROWN	-5808.89+9.32*RAW2T3X	0.96	0.004	272.96
	-6436.96+9.76*RAW3T3X	0.91	0.013	393.97
	-6516.49+5.26*PCA1T3X	0.92	0.009	354.60
	-6288.83+3.61*ADP2T7X	0.99	0.000	114.62
	3404.59-5.19*RAW3T15S	0.79	0.043	587.89
	3499.62-2.69*PCA1T15S	0.83	0.033	539.24
CON/TOT	1.64-0.01*PCA1T7S	0.73	0.066	0.22
	1.31-0.01*ADP1T11S	0.79	0.045	0.19
DEC/TOT	-0.31+0.002*ADP1T11S	0.79	0.045	0.19
	-0.64+0.001*PCA1T7S	0.73	0.066	0.22
DEC/CON	-2.87+0.01*RAW3T11S	0.85	0.026	0.93
	-2.21+0.01*RAW3T15S	0.72	0.070	1.27
	-4.78+0.01*PCA1T7S	0.94	0.007	0.60
	-2.54+0.01*ADP1T11S	0.98	0.001	0.30
	-2.32+0.01*RAW1T15S	0.85	0.027	0.94
DBHS/L	-19.91+0.45*NDVIT11S	0.78	0.046	13.28
	-146.60+0.67*NDVIT7X	0.91	0.013	8.70
	-14.90+0.15*PCA2T15S	0.90	0.014	8.97
	-79.64+0.15*PCA2T15X	0.81	0.038	12.43

Canopy attributes that were highly correlated with a texture variable were then regressed with below-canopy attributes to identify important relationships (Table 2). The regression models revealed that DDEN, CBA, and

DBA were significantly correlated with DECCROWN, CONCROWN, and DECCROWN, respectively as the independent variables (Table 5). The modeled relationships of HEIGHT, CDEN, and TDEN were found not to be statistically significant with any of the canopy attributes.

Table 5. Regression Models that Estimate Stand Attributes from Canopy Attributes

Riparian Forest Attributes	Texture Filter with Coefficients	r^2	P	SEE
HEIGHT	18.73+0.01*CONCROWN	0.65	0.099	9.22
CDEN	21.04+0.02*CONCROWN	0.54	0.156	29.05
DDEN	0.19+0.014*DECCROWN	0.94	0.007	3.62
TDEN	11.49+0.026*TOTCROWN	0.51	0.179	32.25
CBA	-3.06+.007*CONCROWN	0.84	0.029	4.05
DBA	0.003+.001*DECCROWN	0.94	0.005	0.13

4.0 DISCUSSION

4.1 TEXTURE VARIABLE SELECTION

One goal of this paper was to evaluate the texture variables as to their effectiveness in providing information for the interpretation of the ADAR images. The RAW, PCA, and ADP transformations provided information that described the canopy attributes of the five riparian sites. On the other hand, NDVI and PCA provided information on tree-size composition. The standard deviation component of RAW, PCA, and ADP provided more information than the mean component. For example, the mean values only provide information on CONCROWN and DBHS/L, while the standard deviation values not only provide information on CONCROWN and DBHS/L but also on DEC/CON, CON/TOT, and DEC/TOT. To avoid redundancy and reduce the number of texture variables for future analysis then only the standard deviation component should be used. The NDVI transformation should also be deleted because it only provided information on DBHS/L, and this data can be obtained using the PCA stand deviation variable with the same degree of reliability. The relationships of the texture variables with the canopy attributes are complex and difficult to understand without simulation studies because of the heterogeneity resulting from the transformations of the spectral data. Computer simulation studies are currently being developed to help explain these relationships. Also, the applicability of applying the regression models to other forested watersheds of coastal Oregon will be explored after these relationships are developed with the complete Drift Creek data set.

An important consideration in image analysis is the texture unit because it helps define discrete objects of interest (Wang and He, 1990). The texture unit is approximated by the size of the filter. The basic element of interest in the ADAR imagery was the crown of individual trees. The 3x3, 11x11, and 15x15 filters each respectively accounted for 28 % of the significant correlations in this study. The 3x3 filter evaluated a 9 m^2 approximately the average canopy size of the plantation trees. The 11x11 and 15x15 filters accommodated the larger canopy size of the mature conifer and deciduous stands. The results presented here are not conclusive with regards to the best filter size. Obviously, more evaluations are warranted to identify the optimum filter for future texture analysis.

Being able to describe stand height, tree density, and tree-size composition with known confidence using the aerial imagery is important to the characterization of riparian sites and the identification of ecological indicators. The ability to predict CBA, DDEN, and DBHS/L is intriguing since ADAR mainly captures the tops of trees. However, if below-canopy attributes can be estimated by regression models that use canopy attributes as the independent variables (e.g., Cohen and Spies, 1992), then the usefulness of the digital imagery as management and monitoring tools is greatly expanded. The assumption is that below-canopy attributes such as tree density and composition directly influence canopy structure, and therefore they should be correlated. The high correlation of DDEN with a texture variable in light of the low correlations of CDEN and TDEN may be explained by the fact that western red-alder tree canopy gives a different spectral response in comparison with the dominating conifer canopy. HEIGHT and TDEN were not shown to be correlated with any canopy attribute in this evaluation, but these attributes could provide important information for riparian monitoring and management purposes. Continued analyses are justified to develop statistically significant models that predict these attributes.

4.2 ECOLOGICAL INDICATORS

A riparian forest that provides adequate tree cover to maintain water temperature, stabilizes the stream channel, contributes nutrient matter to the stream for aquatic organisms, and has the potential to provide large woody debris to the stream would probably be considered in good condition (Beschta, 1991; Gregory et al., 1991). All these riparian functions are important for maintaining aquatic habitat and water quality. Riparian forest attributes that provide metrics for assessing the ability of riparian forests to meet the above criteria include canopy cover, the proportion of conifer and deciduous trees in the canopy, average stand height, tree density, and the size complexity of the trees in the stand. CONCROWN, CON/TOT, DEC/TOT, and DEC/CON can all be used as monitoring indicators to provide information on canopy structure. The DEC/CON ratio is particularly important for mon-purposes because it should be sensitive to changes in canopy composition over time. For example, an increase in the DEC/CON ratio over several years in Drift Creek Basin may indicate that the competitive dynamics between Douglas fir and western red-alder trees has shifted allowing alder to dominate the stand. This change could result from a variety of reasons such as dieback of the Douglas-fir trees from disease, or debris torrents knocking them over. The rate of the change would provide additional information, a slowly changing ratio could perhaps be reasonably attributed to Douglas-fir dieback. A rapid change in the ratio would support a debris torrent as the causal factor, and it may also indicate that a substantial amount of woody debris recently entered into the stream.

In addition, data on the forest stand attributes obtained from aerial image analysis can also provide information for evaluating management scenarios through the use of model simulations. As an example, data from the DBHS/L, DDEN, CDEN, AND HEIGHT regression equations can be used to estimate the potential for riparian forests to contribute large woody debris to the stream using the model developed by Van Sickle and Gregory (1990). This model predicts the number of pieces and volume of woody debris that may enter a stream from the riparian forest based on tree height, density, size class, and distance information. The model simulations can apply to current riparian conditions with static stand characteristics, or be coupled with a stand dynamics model for long-term projections. The information gained from the modeling scenarios would be important to the development of management strategies. An example from the Pacific Northwest, Douglas-fir and western redcedar trees usually provide larger-sized and more decay-resistant woody debris to streams than western red-alder trees (Harmon et al., 1986). Therefore, riparian management should encourage the growth of mixed-sized Douglas-fir and western redcedar trees to encourage a constant supply of suitable woody debris to the stream.

5.0 SUMMARY AND CONCLUSIONS

Digital, multispectral data were used to characterize riparian sites, and to identify possible ecological indicators for long-term monitoring. The ADAR remote sensing system captured one-meter resolution imagery of 25 different riparian sites in Drift Creek Basin of coastal northwestern Oregon, USA. The imagery of five sites that varied with respect to riparian forest attributes were subjected to texture analysis with 96 different variables. Field data on tree density and DBH were collected from these same sites. The statistical analyses show that the use of the high-resolution, multispectral imagery is a rich source for information on coniferous riparian canopy attributes. Riparian forest attributes such as conifer and deciduous crown cover, total crown cover, tree-size composition were highly correlated with different texture variables, and therefore can be estimated with regression models. In addition, conifer and deciduous crown cover, and total crown cover were correlated with stand density and basal area. These canopy and below-canopy attributes appear to be good indicators or riparian structure because they can be estimated with a known degree of reliability from the regression models, and provide important information on riparian condition.

6.0 ACKNOWLEDGMENTS

The research described in the article has been funded by the US Environmental Protection Agency. This document has been prepared at the EPA Environmental Research Laboratory in Corvallis, Oregon, through contract No. 68-C6-0005 to Dynamac Corp. and through interagency agreement No. DW12936799 with the USDA Forest Service Pacific Northwest Station. It has been subjected to the Agency's peer and administrative review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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NHEERL-COR-2240

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PB98-151244

1. REPORT NO. EPA 600/A-98/061	2.	

4. TITLE AND SUBTITLE Texture analysisof riparian coniferous forest ADAR imagery to identify potential ecological indicators for monitoring.	5. REPORT DATE 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J.R. Barker[1], M.Bollman[1], M.Fiorella[2], G. Bradshaw[3], P.L. Ringold[4]	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS [1]Dynamac Corporation, 200 SW 35th Street, Corvallis, OR 97333 [2]Oregon State University, Corvallis, OR 97331 [3]U.S. Forest Service, Forest Service Science Lab, Oregon State University, Corvallis, OR 97331 [4]US EPA NHEERL, 200 SW 35th Street, Corvallis, OR 97333	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS US EPA ENVIRONMENTAL RESEARCH LABORATORY 200 SW 35th Street Corvallis, OR 97333	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/02

15. SUPPLEMENTARY NOTES:

16. Abstract:
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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
remote sensingk, ecological indicators, riparian forests.		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES: 8
	20. SECURITY CLASS *(This page)*	22. PRICE

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