USING LANDSAT THEMATIC MAPPER IMAGERY TO SUPPORT SALMON RESTORATION EFFORTS IN A LARGE PACIFIC COAST WATERSHED

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INTRODUCTION

Pacific salmon populations have declined precipitously in the past three decades. Their decline has devastated salmon-dependent communities from central California to Puget Sound. Congress has authorized several initiatives to restore salmon populations, including the 1986 Klamath Act (Public Law 99-552). The Act directs the Secretary of the Interior to carry out a 20-year-long Klamath River Basin Fishery Restoration Program. To assist the Secretary in carrying out the program the Act also established a Klamath River Fisheries Task Force of federal, state and local government officials, commercial, angling and tribal fishery stakeholders.

The Klamath Task Force prepared a ***Long Range Plan for the Klamath Riser Basin Conservation Area Fishery Restoration Program.*** The plan organized the available information concerning the Klamath's fish, fisheries, and fish habitat and identified the factors responsible for the basin's salmon population decline. Chief among these appeared to be a long-term decline in water quality from "non-point" pollution sources. Logging and grazing appear to have reduced streamside vegetation which, in turn, increased stream temperatures, accelerated bank erosion and smothered streambeds with sediments.

Information Is Key to Klamath Salmon Restoration Cooperation

While the plan's findings were clear to the Klamath's fish-interested agencies and parties, local landowners and politicians naturally resisted suggestions that traditional watershed uses had contributed to the salmon decline and must, therefore, be modified if the salmon are to be restored. These local interests could easily "veto" the plan by questioning the impacts of grazing and other land and water uses and denying access to the priority stream restoration sites. It was a situation that would require, among other things, abundant information about the condition of the streams and their fish populations. Moreover, the information would have to be presented to the communities in a clear and unequivocal manner.

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Anticipating the continuing need for information to sustain the Restoration Program's monitoring, evaluation and adaptive management needs, as well as the need to convince the broader community of the necessity of specific restoration measures, the Task Force's plan called for the development of a basinwide coordinated information system. Further, the plan specifically recommended that the Task Force evaluate the U.S. Environmental Protection Agency's Stream Reach file as the information system's hydrographic base and Landsat data as a tool for long term change detection, both back in time and forward through the Restoration Program's life.

The coordinated information system was begun in 1992 and dubbed the Klamath Resource Information System, or "KRIS". Reach File data (version 3, or "RF3") was acquired soon thereafter and is being refined to give each stream segment in the huge (10 million acre) watershed, as well as each piece of information about that reach, its own digital address. Finally, Landsat Thematic Mapper (TM) imagery became available to the Restoration Program in 1994 through Interagency Agreement W- 18-567 between the National Aeronautics and Space Administration and the U.S. Fish and Wildlife Service. The Service administers the Restoration Program on behalf of the Secretary and the Task Force.

The Interagency Agreement proposes that the TM data be used to classify the Klamath basin's existing vegetative condition, the specific conditions in the stream corridors that have been prioritized for restoration, and the changes that have occurred in those corridors since Landsat data first became available in the early 1970s.

The Klamath Landsat Vegetative Data Users List Grows

While the specific intent of our Landsat project was to create an information element that would strengthen KRIS' power to support stream and fish population restoration work, it has become increasingly clear that our 1994 Klamath basin vegetative data layer will be valuable to a number of ecosystem restoration efforts now underway in the region. This comes as no surprise since vegetation reflects so many of a site's physical factors, including climate, soil type, elevation, aspect and recent disturbance. It reflects an ecosystem's primary producers and the kinds and extent of terrestrial habitat. In short, an existing vegetation condition map is an indispensable tool for ecosystem assessment and restoration (Scott, et al., 1993).

In addition to the Klamath Fishery Restoration Program the Landsat TM-derived vegetative layer will support the Fish and Wildlife Service's work related to the Northwest Forest Plan, the Department of the Interior's Klamath Basin Ecosystem Restoration Initiative, the U.S. Bureau of Reclamation's Klamath Reclamation Project Operations Plan and the upper Klamath basin ecological restoration projects contemplated in the Oregon Resource Conservation Act of 1996, S. 1662. The data has been prepared for integration, as well, in the State of California's California Environmental Resources Evaluation System (CERES), the National Gap Analysis program, as well as other State and federal spatial databases for Oregon and California.

METHODS

We processed 1994 Landsat Thematic Mapper imagery by computer to create maps of existing vegetation cover throughout selected watersheds. Vegetation maps were overlaid with stream maps to assess near-stream conditions. Near-stream vegetation cover was summarized within a 90 meter stream buffer, thus creating a corridor of analysis 90 meters wide on both sides of each stream, a 180-meter wide total corridor. We compared the shade-producing potential of near stream vegetation in two sub-basins within the Klamath River hydrobasin. In addition to this 1994 vegetation mapping, we also detected changes in vegetation cover over a 20-year time span (1973 - 1992) using co-registered Landsat MSS imagery from 1973, 1984, and 1992. Changes were detected within a region known to have experienced disturbance by fire and logging over this time period in order to demonstrate the utility of spectral change detection for quantifying changes in landscape condition that may cumulatively affect fish habitat.

Mapping the Basin's 1994 Vegetative Condition

Landsat's Thematic Mapper provided electronic, computer-compatible imagery with a ground resolution of 30 meters and a nominal picture element (pixel) size of 30 meters by 30 meters (0.09 hectares). The imagery was acquired by the Landsat satellite between June 22, 1994 and August 9, 1994 with five of the images acquired between July 8 and 17, 1994. The close proximity of the acquisition dates provided seamless coverage during one, early-summer season of plant phenology in a time-frame surrounding the summer solstice, thereby minimizing the effects of terrain shadowing in the imagery. We developed separate spectral signatures for each Landsat scene except for scenes acquired on the same day, for which signatures were developed across multiple scenes. It was necessary to develop unique signatures for each day of image acquisition due to the slightly different spectral properties of the atmosphere on different days.

Our spectral classification system was patterned after California's Wildlife Habitat Relationships (WHR) Classification System (Mayer and Laudenslayer 1988). We could not match the WHR classification system exactly however because spectral signatures from the Landsat Thematic Mapper sensor sometimes failed to discriminate specific WHR habitat types and sometimes discriminated more detail than is required by WHR. Therefore, we modified the WHR Classification System to match the spectral capabilities and limitations of Landsat satellite imagery.

We used a hybrid approach (Fox 1992) to spectral signature development, incorporating both "supervised" and "unsupervised" techniques. Supervised training produced one spectral signature associated with one characteristic vegetation or land cover type. Unsupervised training produced several spectral signatures associated with natural clusters in the multispectral image data, occurring over multiple vegetation types. Both techniques were valuable for vegetation mapping: supervised methods for specific homogeneous vegetation types of special interest, and unsupervised methods, for heterogeneous mixed vegetation types or barren areas. All of the computerized image analysis was accomplished using ERDAS, Imagine software (ERDAS, Inc. 2801 Buford Hwy. N.E., Suite 300, Atlanta, Georgia 30329-2137, USA).

We first selected 150 rectangular regions, each corresponding to a USGS 7.5 minute quadrangle map, as "training regions" for spectral signature development. We produced color composite images and "unsupervised" 28-class, cluster maps of these training regions. These maps were sent to field inspection teams from cooperating organizations (the California Department of Fish and Game, Bureau of Land Management, Fruit Growers Supply Company, Hearst Corporation, Klamath Tribes and the U.S. Forest Service). The field inspection teams provided feedback on how well our unsupervised classifications represented the vegetation mosaic present in the training regions. In addition to this general "how are we doing?" type of information the teams measured field plots in specific vegetation types to provide quantitative information on habitat types, percentage crown closure and tree size.

Spectral signatures were saved from the spectral classes that were reported by the field crews to associate with specific vegetation cover types. The field data plots allowed us to develop spectral signatures by "growing" supervised spectral training areas around ground plot locations, using the ERDAS "SEED" function. We thus defined a spectrally homogeneous area of between 20 and 200 pixels, representing a characteristic vegetation type or land type. After developing supervised spectral signatures (normally 20 to 60) for a region, we added those signatures to the signatures selected from the unsupervised cluster maps. The combined signatures were edited to insure that all signatures were spectrally unique and statistically differentiable. We then used those combined signatures to drive a maximum likelihood classification algorithm over a large area of the image (several training regions). We constrained the classification to a 95 percent probability of inclusion in order to identify pixels that did not fit well into any of the existing spectral classes as "unclassified."

We used unsupervised techniques to develop new signatures from the pixels left unclassified by previous work (normally 10 to 20 percent of the data set). These new, unsupervised signatures were also combined with the previously developed hybrid signatures. After adding the new signatures, the signature file was edited again and used to classify the same region. The thresholding process was repeated and the entire unsupervised process was repeated once more, to classify remaining areas of the image resistant to previous classification. We thus classified 98 percent of the pixels, realizing that 100 percent classification is virtually impossible with the maximum likelihood classifier, when constrained probabilistically. The rationale is that it is bettei to fail to classify two percent of the image than to classify that two percent into the wrong classes.

Preliminary classification results were printed at 1:24,000 scale for distribution to the field inspection teams. The teams provided final review of the signatures and corrected any mislabeled signatures. Their corrections were incorporated into the final classification maps.

Detecting Changes in Vegetation Cover Over a 20-year Period

We detected changes in the landscape over the past twenty years using the North American Landscape Characterization (NALC) data purchased by NASA's Mission to Planet Earth. The NALC data sets are comprised of co-registered Landsat Multispectral Scanner (MSS) imagery from the early 197Os, early 1980s and early 1990s assembled by the EROS Data Center, U.S. Geological Survey, Sioux Falls, South Dakota. These images provided a ground resolution of 79 meters, having a nominal picture element size 79 meters by 79 meters (0.62 hectares). We detected changes in multispectral reflectance associated with increases in green vegetation cover, and decreases in green vegetation cover, between 1973 and 1984, and then, again, between 1984 and 1992. We selected an area centered on South Fork Mountain in northwestern California known to be disturbed by logging and fire during the past 20 years, for change detection analysis.

Before detecting changes in the landscape, changes in image brightness caused by differences in the optical properties of the atmosphere and sun angle geometry were greatly reduced by normalizing the data with the "NEVI", or Normalized Difference Vegetation Index (Jennies 1996). This ratio difference image is the result of dividing the difference between near infrared brightness level (digital number, or DN) and visible red DN by the sum of near infrared DN and visible red DN:

(MSS band 4 - MSS band 2) / (MSS band 4 + MSS band 2)

This produced a single band, NEVI image for each date of co-registered MSS image data. Brighter values in these images indicated a high density of green vegetation, while darker values indicated a low density of green vegetation. Barren areas were especially dark, and irrigated pasture was especially light in the NEVI images.

The 1984 NEVI image was subtracted from the 1973 NEVI image to detect changes during this eleven year period (1973 - 1984). The resulting difference image contained dark values associated with areas experiencing a large increase in green vegetation cover during the time period. Areas undergoing early plant succession during the time period, following disturbance by fire or logging, were typically characterized by large increases in green vegetation cover.

Light values in the difference image were associated with areas experiencing a large decrease in green vegetation cover during the time period. Areas disturbed by fire or logging during the time period were typically characterized by large decreases in green vegetation cover. The process was repeated with the 1992 image by subtracting the 1992 NEVI image from the 1984 NEVI image to detect changes during this eight year period (1984 - 1992).

RESULTS

The vegetation classification system that we developed from spectral data and used to map existing vegetation in 1994 is shown in Table 1. The Landsat derived habitat type and its symbol are on the left side of Table 1. Our classification was developed to be as similar as possible to California's Wildlife Habitat Relationships (WHR) Classification System (Mayer and Laudenslayer 1988). WHR classes that were included in the Landsat type are listed in parentheses in the middle column. All discriminated stages of WHR size and canopy closure or zone and substrate class are listed in the right column. A typical map symbol was: SHGD (Greenleaf Shrub, closure class D) or MCP5M (Mixed Pine, size class 5, closure class M).

Spectral signatures from the Landsat Thematic Mapper sometimes failed to discriminate a specific WHR habitat type. Such an information loss occurred when the WHR label contains a geographic reference that did not necessarily indicate a different spectral signature, or even a different vegetation composition. For example, valley oak woodland and coastal oak woodland were aggregated to form a mixed oak woodland class.

Generalization of the classification was also required when two or more vegetation types and/or stages had very similar spectral signatures. This occurred extensively in the tree types. For example, the WHR types Sub Alpine Conifer, Red Fir, White Fir, Sierra Mixed Conifer, Klamath Mixed Conifer, Douglas Fir and Redwood (when not containing hardwood) were all combined to form the Landsat type "Mixed Conifer". In some cases the spectral signatures provided more information than the WHR type. This occurred when the WHR type contained multiple canopy types that had very different spectral signatures (e.g. needle-leaf and broad-leaf mixtures). When a spectral difference allowed for finer discrimination than the WHR system, we discriminated those specific classes. For example, the WHR type Montane Hardwood Conifer (MCH) was divided into conifer dominated mixtures (MCH) or hardwood dominated mixtures (MHC). Likewise, Coast Redwood (RDW) was divided into pure conifer (MCN) or various mixtures of conifer and hardwood, depending on the dominance of the hardwood component (MHC or MCH).

We did not label any spectral class with a symbol implying land-use, such as: agriculture, crops, cropland, orchard, vineyard, residential, urban, roads, fallow, pasture, etc. We labeled these areas according to their vegetation cover (or lack there of) as defined by the classes we used. We did not label any spectral class with a reference to geographic location or geographic shape, such as: river, marsh, lake, bay, ocean, coastal ___, valley ___, etc. We labeled these areas according to their land cover condition. This is because spectral signatures recognize surface features of individual pixels as a spectral pattern without regard to where that feature is located, or to what landscape feature that pixel belongs. For example, water in a lake looks like water in a river to a spectral signature classifier operating with satellite imagery.

Table 1 The Habitat Type Classification System used to map existing vegetation from 1994 Landsat Imagery. Equivalent California Wildlife Habitat Relationships (WHR) Types are shown in Parentheses.

GENERAL TREE TYPES

HABITAT TYPE	Symbol	Included WHR Types	Identified Stages (WHR tree size & closure[1])
(1) Mixed Conifer (Needle-leaf. <20% broad-leaf)	MCN	(SCN, RFR. SMC. WFR. KMC. RDW. DFR. JPN. PPN. EPN, CPC. LPN)	2S 2P 2M 2D 3S 3P 3M 3D 4S 4P 4M 4D 5S 5P 5M 5D The above classes repeat for all tree types.
1A. Mixed Fir (Mapped when possible)	MCF	(SCN. RFR. SMC. WFR. KMC. RDW. DFR)	
1B. Mixed Pine (Mapped when possible)	MCP	(JPN, PPN. EPN. CPC. LPN)	
(2) Mixed Conifer-Hardwood (Mixed needle-leaf & broad-leaf. >50 % Needle-leaf)	MCH	(MHC. KMC, DFR. JPN. PPN. EPN. RDW. CPC)	
(3) Mixed Hardwood-Conifer (Mixed broad-leaf & needle-leaf. >50 % broad-leaf)	M HC	(MHC. MHW. BOP)	
(4) Mixed Hardwood (Broad-leaf. <20% needle-leaf)	MHW	(MHW. MHC. MRI. VRI. EUC. ASP)	
(5) Mixed Oak Woodland (Oak dominated broad-leaf)	MOW	(VOW. COW. BOW)	
(6) Mixed Juniper/Pinyon	MJN	(PJN. JUN)	

WHR tree size classes are:

Size Class	DBH Range (inches)
2	1- 6
3	6- 11
4	11-24
5	>24

WHR canopy closure classes are:

Closure Class	Canopy Closure (%)
S	10 - 24
P	25 - 39
M	40 - 59
D	60 - 100

NOTE 1: We did not discriminate WHR size class 1 for trees since areas containing seedlings < 1 inch in diameter are normally, spectrally dominated by the companion vegetation.

GENERAL SHRUB TYPES

HABITAT TYPE	Symbol	Included WHR Types	Identified Stages (WHR shrub closure[1])			
			S (10-24)	P (25-39)	M (40-59)	D (60-100)
			Percent crown closure			
Greenleaf Shrub (dominated by green leaves)	SHG	(ADS. MCP. MCH. CSC)	S	P	M	D
Deadstick Shrub (dominated by woody sticks)	SHD	(ASC. MCH. CRC)	S	P	M	D
Soft Shrub (lacking stiff woody stems)	SHS	(BBR. LSG. SGB)	S	P	M	D

NOTE 2: We did not discriminate WHR. "size" (actually maturity) classes for shrubs.
Table 1. Continued.

GENERAL HERBACEOUS TYPES

HABITAT TYPE	Symbol Included WHR Types	Identified Stages (WHR herb. closure')			
Dead Grass/Forb, (dominated by dead leaves)	GSD (PGS. AGS. CRP. PAS)	S (2- 9)	P (10-39)	M (40-59)	D (60-100)
		Percentage of herbaceous cover			
Green Grass/Forb (dominated by live leaves)	GSG (WTM. PGS. AGS. OVN. CRP. PAS)	S	P	M	D
Wet Meadow/Marsh	GSW (WTM. FEW. SEW)	S	P	M	D

NOTE 3: We did not discriminate WHR height classes for herbaceous types.

GENERAL BARREN TYPES

HABITAT TYPE	Symbol	Included WHR Types	Idcntificd WHR Zones[4]
Snow & Ice	BSI	(none dcfi ncd)	(none defined)
Soil	BSL	(RIV, MAR. EST. LAC. URB)	2
Gravel/Rock/Talus (includes concrete and asphalt)	BGR	(RIV. MAR. EST. LAC. URB)	2

NOTE 4: We combined WHR Zones 3 & 4 to form a new Zone 2 (exposed during satellite overpass). We did not discriminate WHR substrates. BGR and BSL types occurring in or near rivers and lakes are spectrally identical to BGR and BSL types occurring on upland sites.

GENERAL AQUATIC TYPE

HABITAT TYPE	Symbol	Included WHR Types	Identified Zone'
Water	WTR	(RIV. MAR. EST. LAC)	1

NOTE 5: We combined WHR Zones 1, 2 & 3 to form a new Zone (submerged during satellite overpass). We did not discriminate WHR substrates.

Final maps of existing vegetation were prepared in electronic and hard copy forms (Figures 1 and 2). The electronic versions of these maps are fully attributed, "raster" data layers that may be incorporated into a Geographic Information System (GIS) such as Arc/INFO or ArcView. The 0.09 hectare (0.22 acre) grid cell, vegetation maps shown in these figures each cover one specific watershed within the Klamath River Basin in north-central California. The Scott River Basin (Figure 1) is characterized by mountainous, forested terrain in the upper reaches, a broad, flat valley in the middle reaches and mountainous terrain in the lower reaches. The east side of the basin is dominated by hardwood forest and shrubs while the west side supports conifer forest cover. The Shasta River Basin (Figure 2) is located further east from the Scott and reflects the hotter and drier climate. Vegetation in the Shasta Basin contains a larger proportion of non-forest types as shown in Figure 3.

The accuracy of the final maps has not yet been assessed in a formal, post classification assessment. However, the accuracy was constantly assessed during the classification process and the classification system was modified to insure accurate classifications. Whenever any doubt about spectral discrimination was indicated, the classification was generalized to a level that did produce reliable discrimination. We have every reason to believe that formal accuracy assessment will report accuracy levels of between 75 and 85 percent.

GIS, Map Analvsis

Returning to the project's original objective, we constrained the vegetation classification to the area adjacent to two priority restoration streams in the Klamath River basin. The Scott River Watershed is shown in Figure 4 and the Shasta River Watershed is shown in Figure 5. We displayed and summarized the 1994 existing vegetation map for a 90-meter buffer zone, either side of the stream vectors in the watersheds. Stream information was obtained from RF3, EPA River Reach file data. The 90-meter buffer comports with the stream protection standards of the President's Pacific Northwest Forest Plan. The buffer was calculated by adding three, 30-meter Landsat TM pixels in each direction from the pixel in which the stream vector occurred, thus construction a corridor of 180 meters total width.

Our analysis provides a tool which allows a quick assessment of streamside shading vegetation. Since the stream temperatures are so critical to the growth and survival of young salmon, protecting and restoring shade-producing vegetation is a major focus of the Klamath fishery restoration.

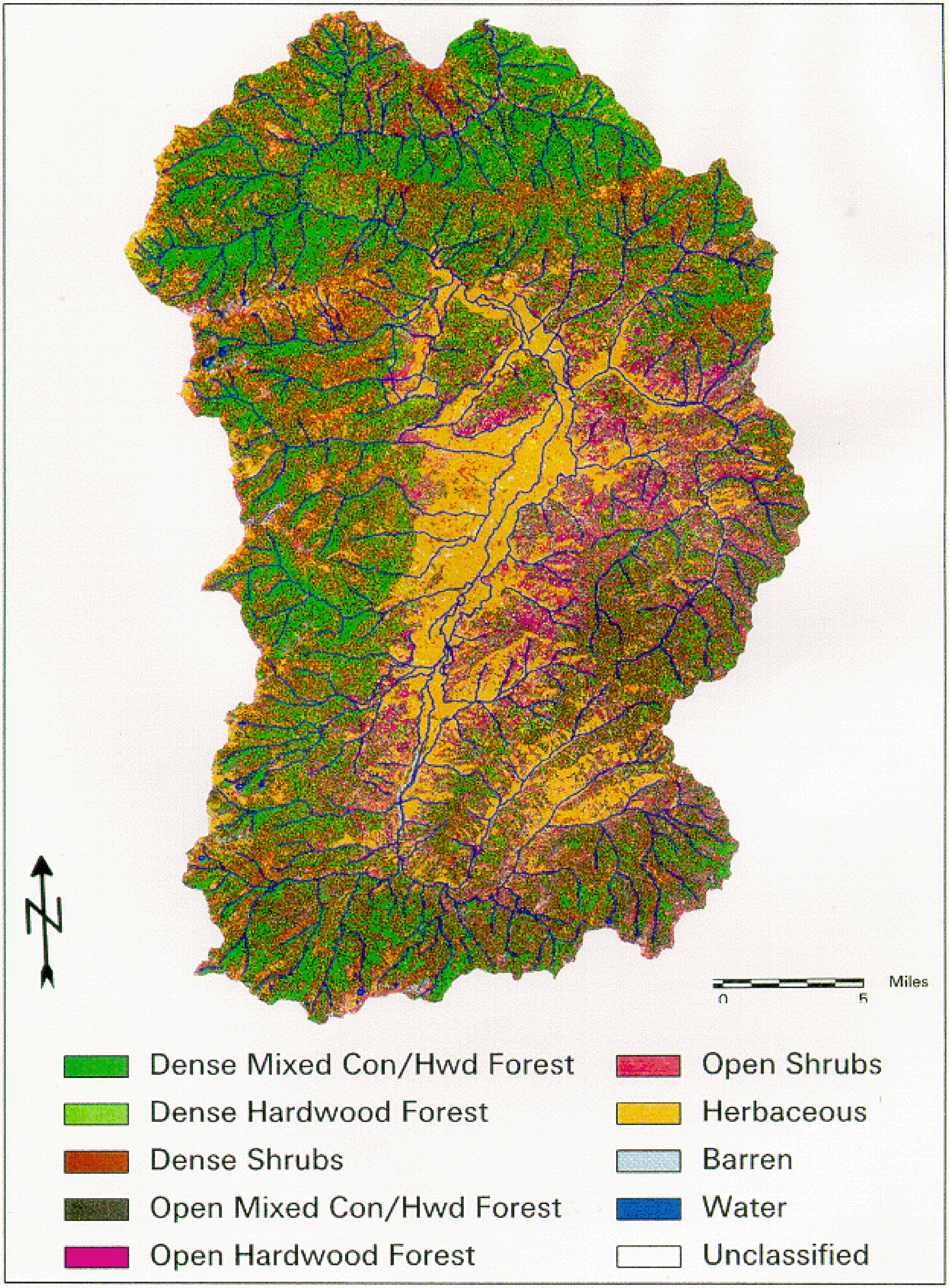

Figure 1. The 1994, existing vegetation map of the Scott River Watershed, Klamath River Basin, California. The legend is aggregated from Table 1.

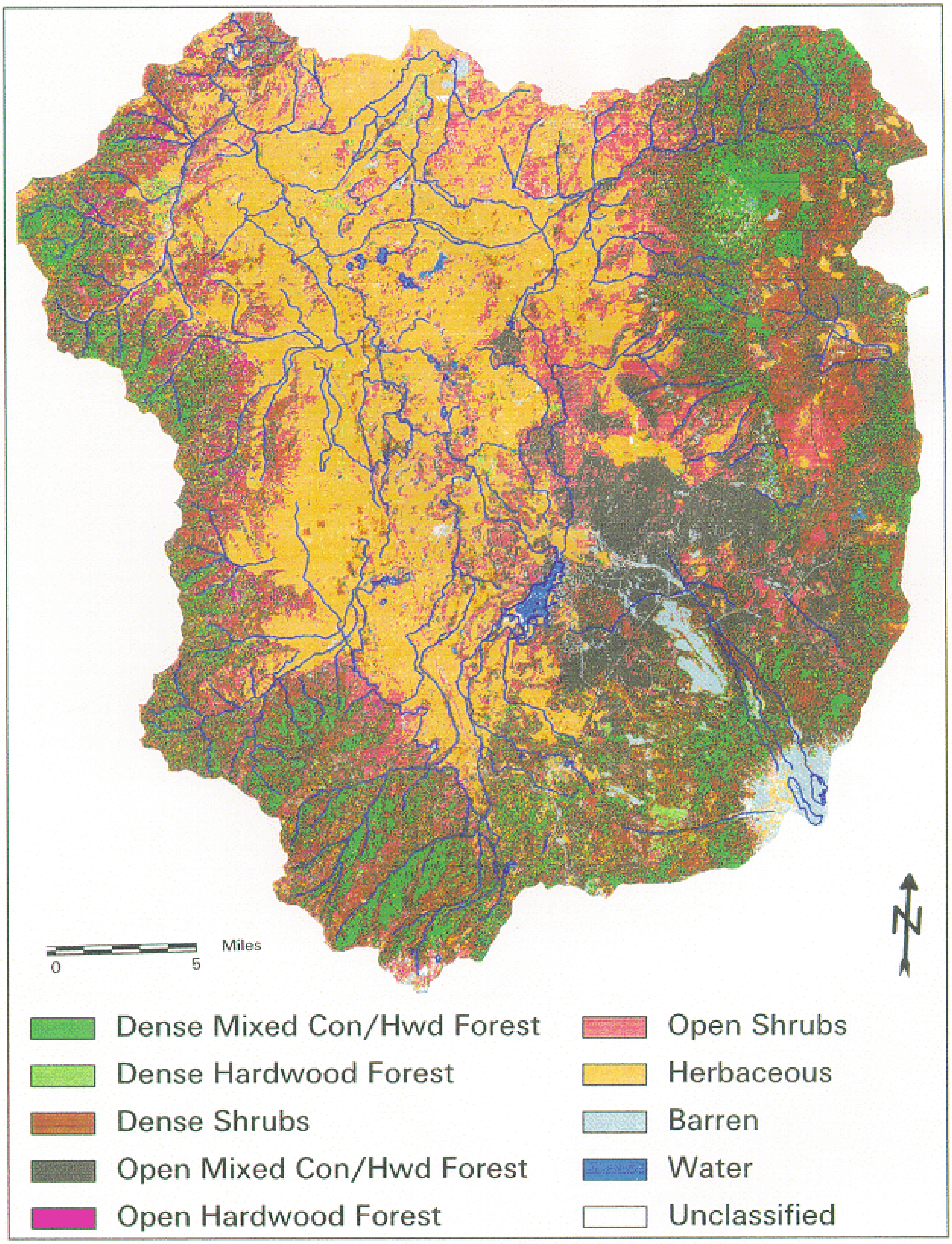

Figure 2. The 1994, existing vegetation map of the Shasta River Watershed, Klamath River Basin, California. The legend is aggregated from Table 1.

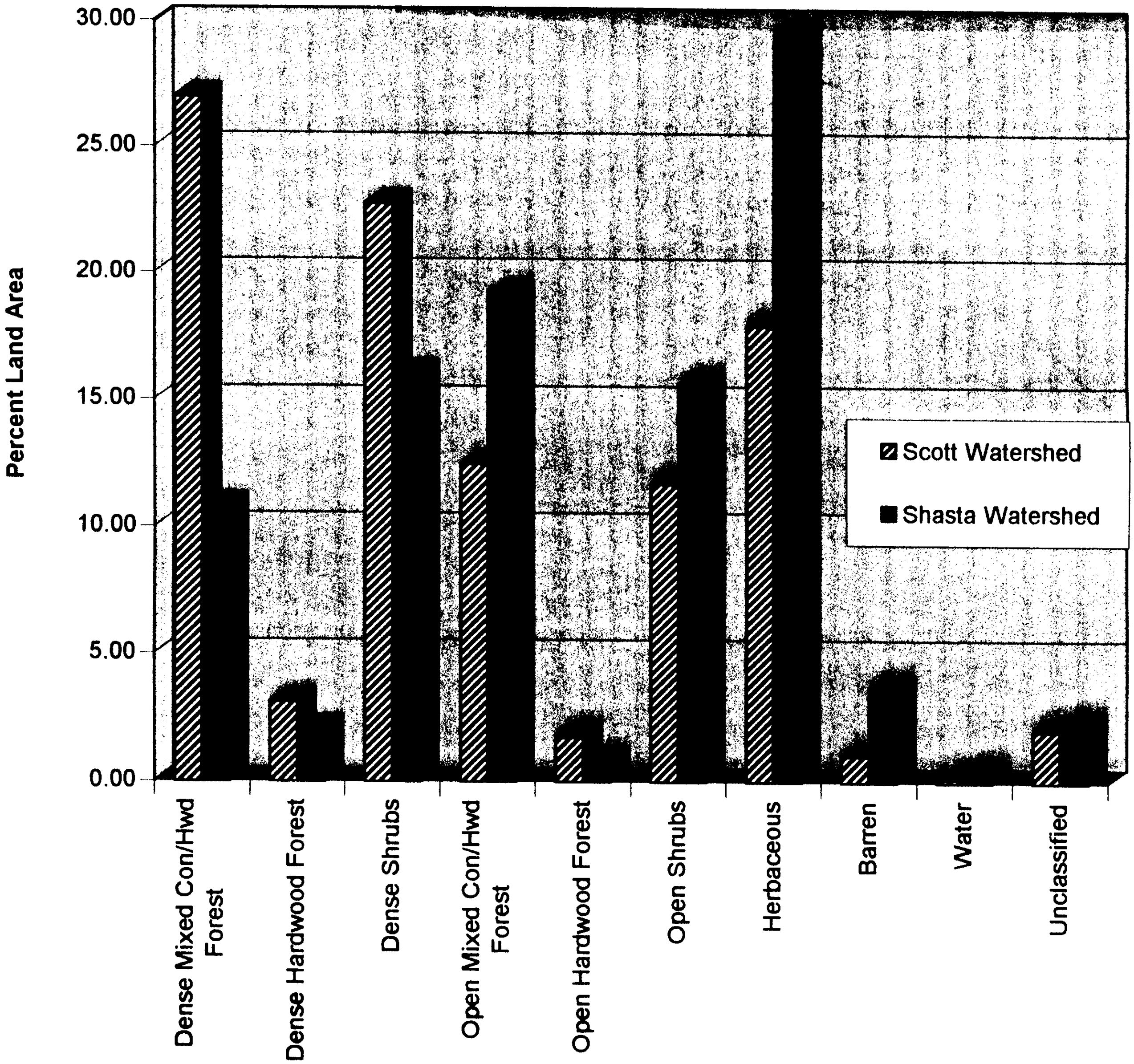

Figure 3. The relative percentage of land area by vegetation type for the Scott River Watershed and the Shasta River Watershed. Classes aggregated from Table 1.

We summarized the land area associated with each aggregated, shade-producing vegetation class for these two watersheds (Figure 6). This comparative graph allows a rapid visual assessment of the relative proportion of shade producing vegetation near the streams in these watersheds. A simple visual comparison immediately communicates that the Shasta River watershed has less shade-producing vegetation along its streams than the Scott. This suggests that riparian vegetation restoration is of even greater urgency in the Shasta than in the Scott, a matter upon which the 1994 Landsat maps and the Task Force's 1991 long range plan agree.

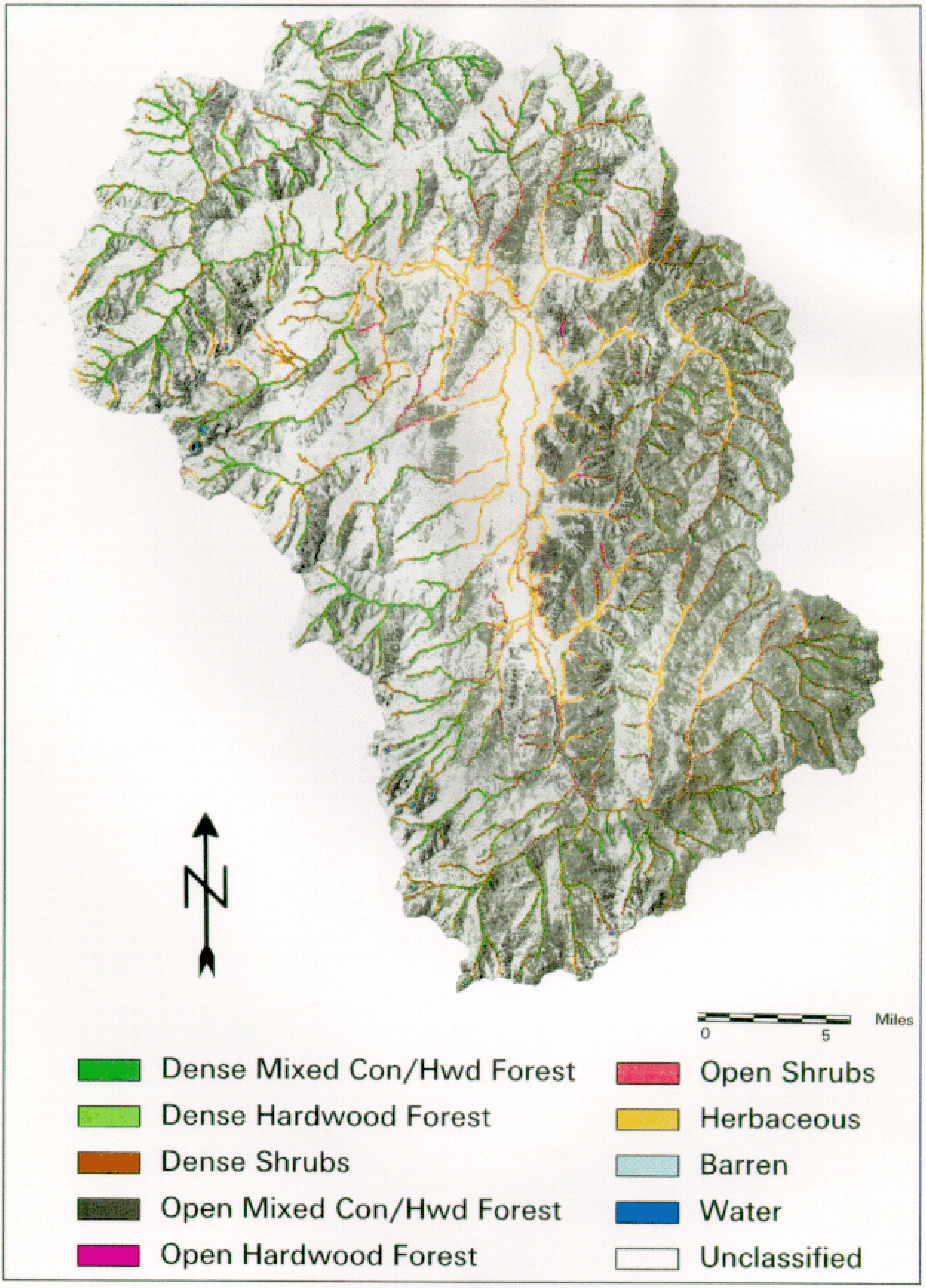

Figure 4. The 1994, existing vegetation map of the Scott River Watershed, constrained to a 90-meter buffer, Klamath River Basin, California. Classes aggregated from Table 1.

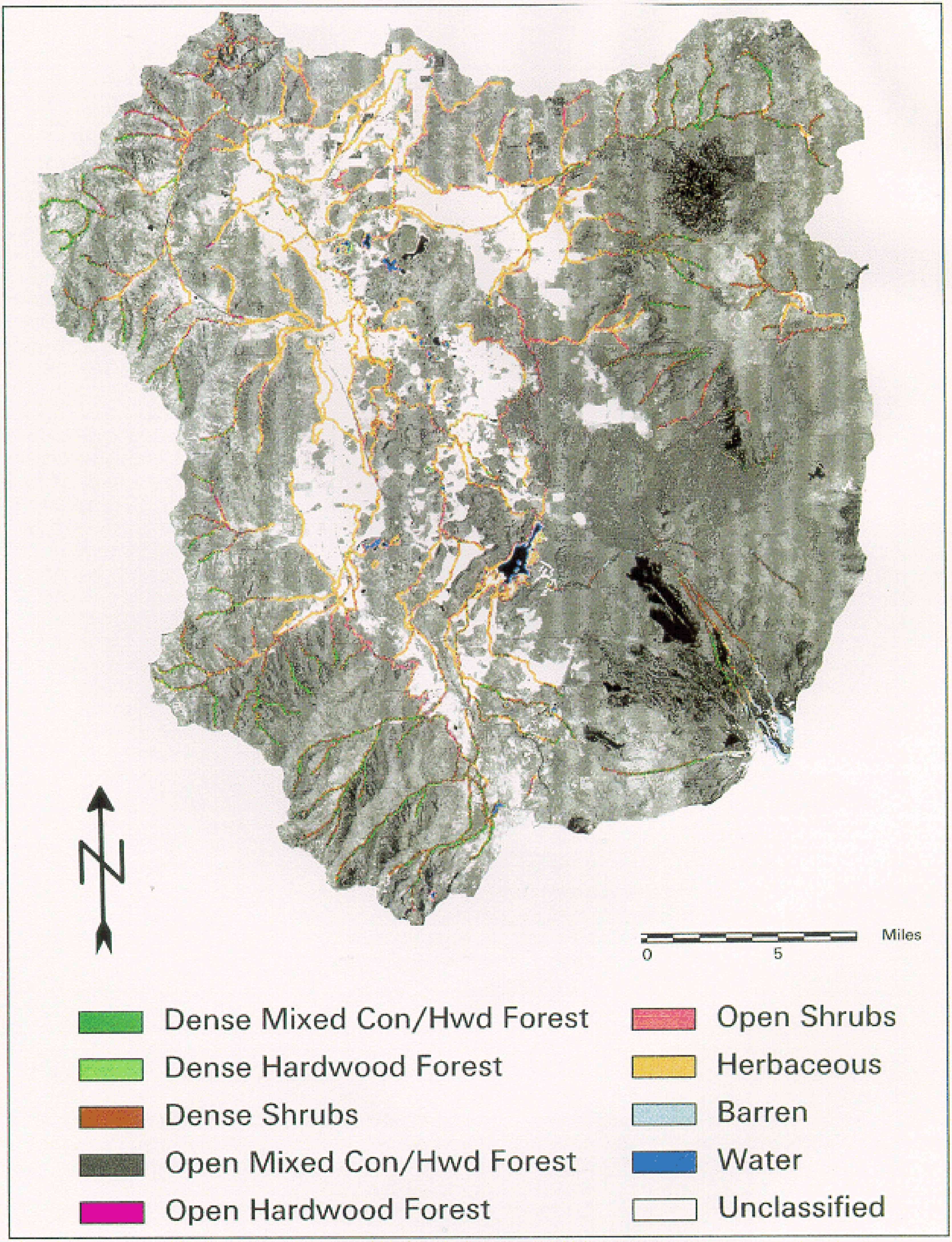

Figure 5. The 1994, existing vegetation map of the Shasta River Watershed, constrained to a 90-meter buffer, Klamath River Basin, California. Classes aggregated from Table 1.

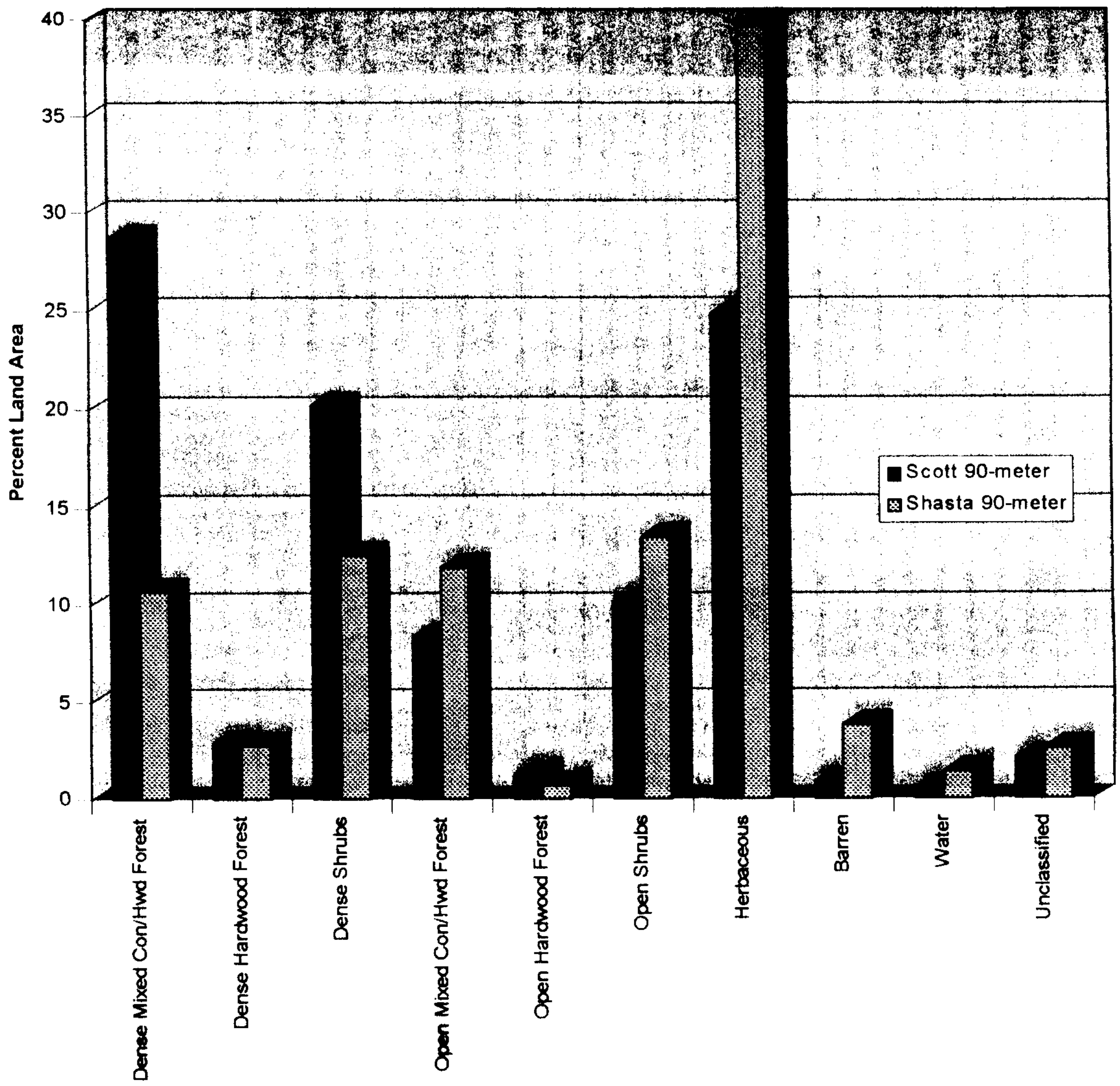

Figure 6. Area summaries of vegetation classes within a 90 meter buffer zone around streams in the Scott and Shasta River Watersheds, Klamath Basin, California.

<u>Detecting Changes in Vegetation Cover Over a 20-year Period</u>

Two change detection maps are illustrated here: changes between 1973 and 1983 (Figure 7) and changes between 1983 and 1992 (Figure 8) are illustrated for the South Fork Mountain region in northwestern California. These maps cover an area approximately 28 miles by 36 miles (645,000 acres). Rectangular coverage of USGS 7.5' Quadrangle Maps is shown in black on the Figures. These maps provide a tool for assessing vegetation changes at the landscape level. As indicated by the color codes, the landscape was characterized by moderate increases in green vegetation cover during the period, 1973 to 1984 (Figure 7). Rectangular patches of bright green indicate rapid early succession during this time period, probably caused by logging immediately before this period. Geometrically shaped areas showing moderate to minor green vegetation increases probably represent later, slower succession during this period, after logging a relatively long before this time period.

In stark contrast, this same landscape experienced significant decreases in green vegetation cover during the more recent time period, 1984 to 1992 (Figure 8). Geometric red areas represent substantial green vegetation decreases caused by clear cut logging during this time period. Large purple to magenta areas represent minor to moderate decreases in green vegetation associated with wildfires during this time period.

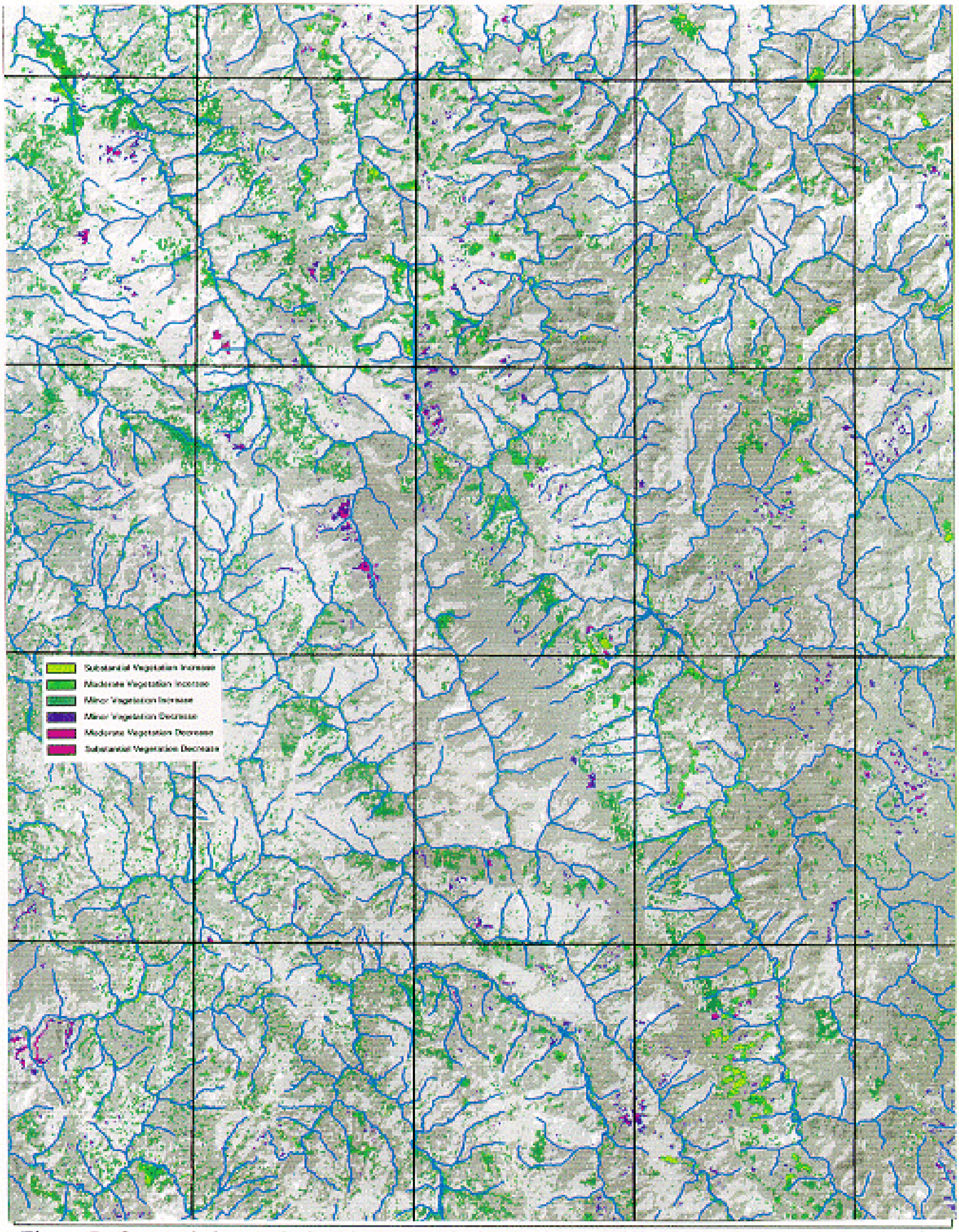

Figure 7. Spectral change during the period 1973 to 1984, South Fork Mountain, northwestern California. Rivers in blue, USGS 7.5' Quads in black, 1 in. = 4 miles.

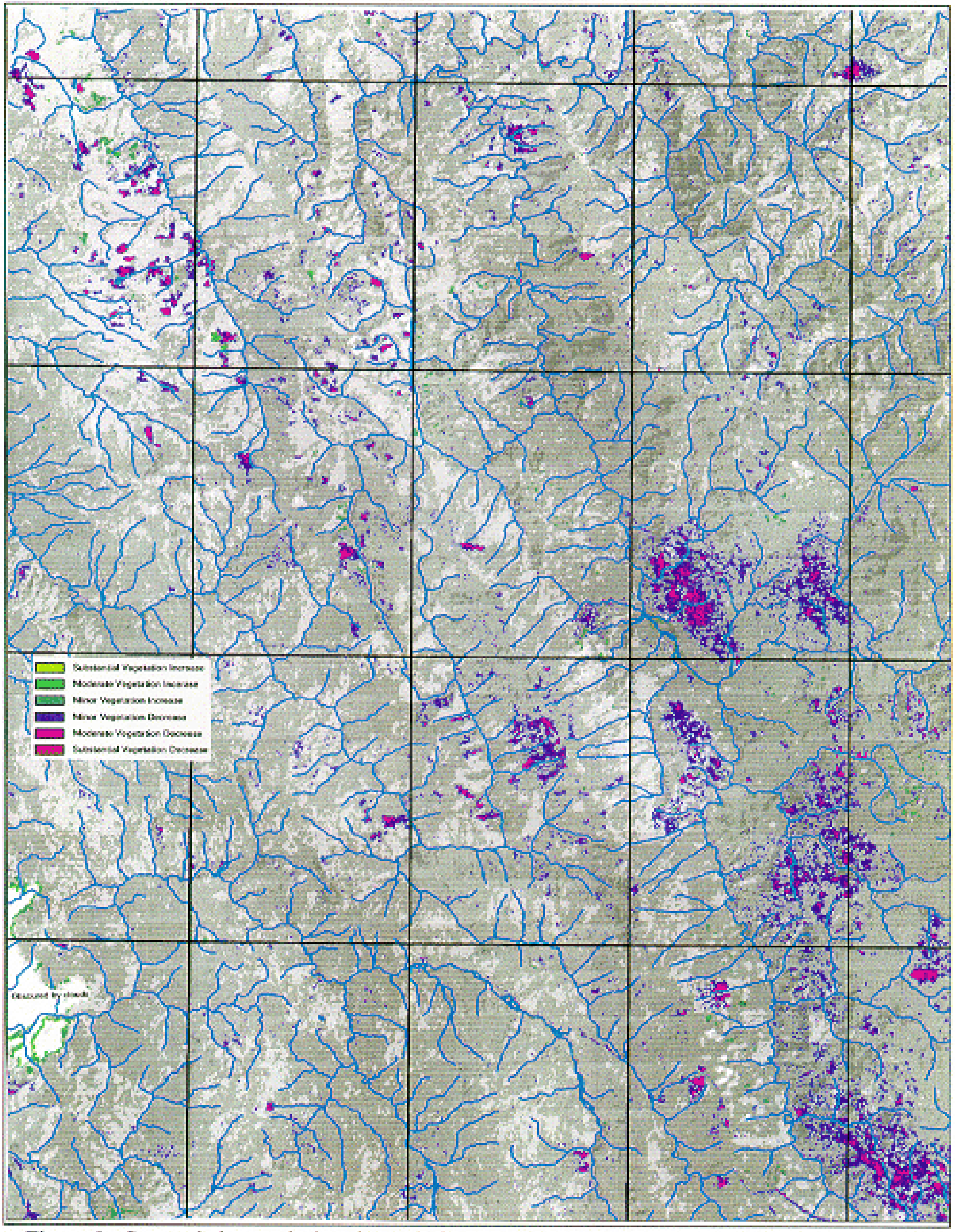

Figure 8. Spectral change during the period 1984 to 1992, South Fork Mountain, northwestern California. Rivers in blue, USGS 7.5' Quads in black, 1 in. = 4 miles.

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