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Identifying Regional Water Quality Patterns and Their Relationships with Terrestrial Ecosystems and Fish Distributions

T. W. McDaniel
C. T. Hunsaker
J. J. Beauchamp

Environmental Sciences Division
Publication No. 2728

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ENVIRONMENTAL SCIENCES DIVISION

IDENTIFYING REGIONAL WATER QUALITY PATTERNS AND THEIR RELATIONSHIPS WITH TERRESTRIAL ECOSYSTEMS AND FISH DISTRIBUTIONS

T. W. McDaniel,[1] C. T. Hunsaker,
and J. J. Beauchamp[2]

Environmental Sciences Division
Publication No. 2728

[1]Present address: Regional Air Pollution Control Agency, P. O. Box 972, Dayton, Ohio 45422
[2]Engineering Physics and Mathematics Division, Oak Ridge National Laboratory.

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ABSTRACT

MCDANIEL, T. W., C. T. HUNSAKER, and J. J. BEAUCHAMP. 1986. Identifying regional water quality patterns and their relationships with terrestrial ecosystems and fish distributions. ORNL/TM-9916. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 74 pp.

A multivariate statistical method for analyzing spatial patterns in regional water quality was developed using existing water quality data in the U.S. Environmental Protection Agency's STORET system. Regional patterns of terrestrial ecosystems have been described and mapped for various management and scientific purposes. Most of these methods ignored or placed little emphasis on the regional patterns in aquatic ecosystems even though they are bounded by the terrestrial systems and affected by their functioning. The procedure we used examined geographical patterns for selected water quality variables in Kansas and Georgia. Using multivariate statistical techniques, it was able to distinguish regions with water quality very different from average conditions (as in Georgia) but did not discriminate well between regions that did not have diverse conditions in water quality (as in Kansas). The observed regional water quality patterns were compared with terrestrial ecosystem patterns. In addition, fish distributions were compared with regional patterns in water quality to determine if there was an association between them. In Georgia, water quality patterns were similar to ecosystem patterns and fish distributions, but correlation was not as good for the more homogeneous landscape in Kansas. Identifiable relationships between climate, lithology, terrestrial ecosystems, water quality, and fish

distributions should allow the development of an integrated terrestrial-aquatic ecosystem classification scheme that would be a valuable tool for resource management and regional assessments.

1. INTRODUCTION

Government agencies are required by law (e.g., Forest and Rangeland Renewable Resources Planning Act of 1974, National Forest Management Act of 1976, and Soil and Water Conservation Act of 1977) to prepare regional and national assessments of various natural resources (Nelson et al. 1978). The task of making these large-scale management decisions involves the use of large quantities of data, often collected by various agencies using different techniques. With an increase in the number of resources to be analyzed, the complexity of the decision-making process has greatly increased. This is compounded by the additional problems associated with detecting large-scale ecological spatial patterns from data collected nonrandomly in time and space, and the proper organization of the data becomes extremely important. Typically, a hierarchical classification scheme has been used to organize the data into a useable framework with applications at more than one level of interest (e.g., national, regional, local). Attempts have been made to produce hierarchical, multiple-resource classification systems for the management of natural resources (Bailey 1978, SCS 1981). These systems organize areas on the basis of climate, topography, and vegetation, but place little emphasis on aquatic ecosystems (Lotspeich 1980, Rowe and Sheard 1981). It has been suggested that watershed boundaries and information about aquatic ecosystems be included in these resource classifications because aquatic systems respond to the functioning of terrestrial ecosystems (Lotspeich and Platts 1982). Likewise, fish are exposed to the water quality conditions that reflect the conditions of the watershed's

ecosystem. Hubbs (1957) and Pflieger (1975) recognized that fish distributions followed the terrestrial biotic province boundaries in Texas and Missouri, respectively. In Oklahoma, Miller and Robison (1973) noted a "considerable overlap in the patterning of faunal groups among the vertebrates studied (reptiles, fish, mammals)." These authors believed that the similarities were due to climatic and physiographic factors influencing the terrestrial and aquatic ecosystems in similar ways (Miller and Robison 1973). Ross (1963) stated that environmental factors influence streams inversely with the size of the stream so that the biota of small streams should be associated with the terrestrial biomes more than the biota of large streams and rivers. Similarities between water quality patterns, terrestrial ecosystem patterns, and fish distributions would reinforce the usefulness of a resource classification scheme that integrates terrestrial and aquatic ecosystems.

The objectives of this study were (1) to determine if spatial patterns in regional water quality could be detected using currently existing data and (2) to compare the observed patterns in regional water quality with fish distribution patterns and with resource classification systems currently used by the U.S. Forest Service and the U.S. Department of Agriculture to determine if regional water quality patterns could be used in large-scale management decisions. To accomplish this objective, statistical procedures were used to determine if significant differences exist between water quality data for watershed units and to determine those watershed units with similar water quality characteristics.

2. METHODS

The state of Kansas was chosen to develop a procedure for evaluating patterns of regional water quality because (1) the state has regularly sampled water quality data for most of the state, (2) it has published data on fish distributions, and (3) it is divided into several terrestrial biotic divisions. Kansas has published fish distributional surveys and studies relating distributions to environmental variables (Cross 1967, 1970; Smith and Fisher 1970; Lessenden 1976). If fish distributions were limited by their zoogeography, more than by environmental variables, then there would be little information gained by comparing their distributions to water quality patterns. However, Cross (1967) states that fish distributions in the state are influenced more by local environments than by historical drainage patterns. As a result, these distributions should also relate to patterns in water quality. In addition, the state was divided into several terrestrial biotic divisions by Bailey's (1978) ecoregions map and by the Soil Conservation Service's (SCS 1981) major land resource map.

Similarly, Georgia was selected as a second validation area for the procedure. Georgia had ample water quality data, fish distribution and habitat data (Dahlberg and Scott 1971), and distinct terrestrial ecosystem divisions as described by Bailey (1978) and the SCS (1981).

Water quality station information was retrieved from the Environmental Protection Agency's STORET system (USEPA 1977) by cataloging unit, the smallest U.S. Geological Survey (USGS) watershed

unit at a national scale (average size of 181,000 ha). Cataloging units are subwatersheds within the accounting unit watersheds. The criteria for selection of stations were: period of record, quantity and frequency of data on water quality variables of interest, and location of the monitoring stations relative to point sources of pollution. The time period chosen for this study was calendar years 1978 through 1982. Stations with data extending through all or most of this period were selected. A minimum of ten observations collected throughout these years was necessary for a station to be used in this study. The locations of the water quality stations were mapped and compared to maps of the location of each National Pollutant Discharge Elimination System (NPDES) permitted discharger so that stations downstream of major, point-source pollution areas could be excluded from the analysis. These were removed so that the water quality patterns detected in the analysis could be assumed to result from natural environmental factors acting on the ecosystem.

Several univariate and multivariate statistical procedures from the Statistical Analysis System (SAS) were used to analyze the data. Because the SAS multivariate statistical routines eliminate all observations with missing values, the daily observations from all stations within a cataloging unit were combined so more variables could be used in the analyses and all of the stations within each cataloging unit could be used. As a result, the combined data favored the stations in the cataloging unit that had more observations in the period of record. Simple statistics such as mean, upper decile, and lower decile were computed and used as the individual observations for water quality within a cataloging unit.

Because cataloging units are hierarchically grouped into accounting units (the next larger USGS watershed unit), the accounting units were defined as the class variables in the multivariate statistical analyses. Analysis of variance techniques were used to determine the variables with significant ($P < .05$) between-class variation, where accounting units are defined as classes. Only these variables were retained for further analysis (see Section 4). When two variables exhibited a high correlation, the least significant variable was removed from the analysis. The selected variables were used in a canonical discriminant analysis, using the SAS procedure CANDISC, to test for significant differences between the accounting units and to provide a visual representation of the positions and orientations of the different accounting units relative to each other. From the original input variables, this multivariate analysis creates new variables (canonical variables) that are linear combinations of the original variables. In addition, the new canonical variables are created to maximize the separation between the means of the observations from the different accounting units. A good graphic method for summarizing the output from this analysis is a plot of the mean values of the first two canonical variates, which are the two variates accounting for most of the ability to separate the accounting units, for each accounting unit and its associated confidence region.

A different discriminant analysis (DISCRIM) was performed to test the homogeneity of the within-class covariance matrix. The DISCRIM procedure also uses the linear discriminant function to estimate the

probability of a cataloging unit being misclassified into an accounting unit on the basis of the observed water quality characteristics (SAS 1982).

Some statistical analyses were required on the Georgia fish distribution data to make it similar to data available for Kansas. These data reported only the historical presence or absence of each fish species in 15 river basins in Georgia (Dahlberg and Scott 1971). The data were clustered into groups of fish with similar distributions for comparison with regional water quality patterns. An agglomerative, hierarchical clustering technique was used to group the fish with similar distributions together. The CLUSTER procedure in SAS performed the classification using Ward's Method, and a dendrogram was produced by the TREE procedure (SAS 1982).

3. STUDY AREAS

Kansas and Georgia were the two regions chosen for which a method for evaluating regional water quality patterns would be developed. These two areas have different terrestrial ecosystem types and dominant environmental variables. Kansas is still predominantly covered by grasslands, much of which is grazed. Climate may be the major environmental factor influencing biological processes. In contrast, Georgia is more developed, with many of the native forests replaced by agricultural land uses. The physiography of Georgia, with its mountains, plains, and coastlines, exerts a strong influence on ecological patterns in the state. The contrast between a region with relatively uniform environmental conditions and a region with diverse environmental conditions permitted an evaluation of the methods for determining regional water quality under different controlling factors.

The boundaries of regions in this study are natural watershed boundaries so they do not conform to the political state boundaries. The USGS has a hierarchical classification system for watersheds. The smallest watershed on the regional scale is the cataloging unit which has a unique eight-digit identifier. Cataloging units differ only in the last two digits of their identifier and are grouped to form accounting units identified by the first six digits. Similarly, accounting units are arranged into subregions and regions.

3.1 KANSAS

The 120 water quality stations in 50 cataloging units used in the Kansas analysis are mapped in Fig. 3.1. The stations used in the

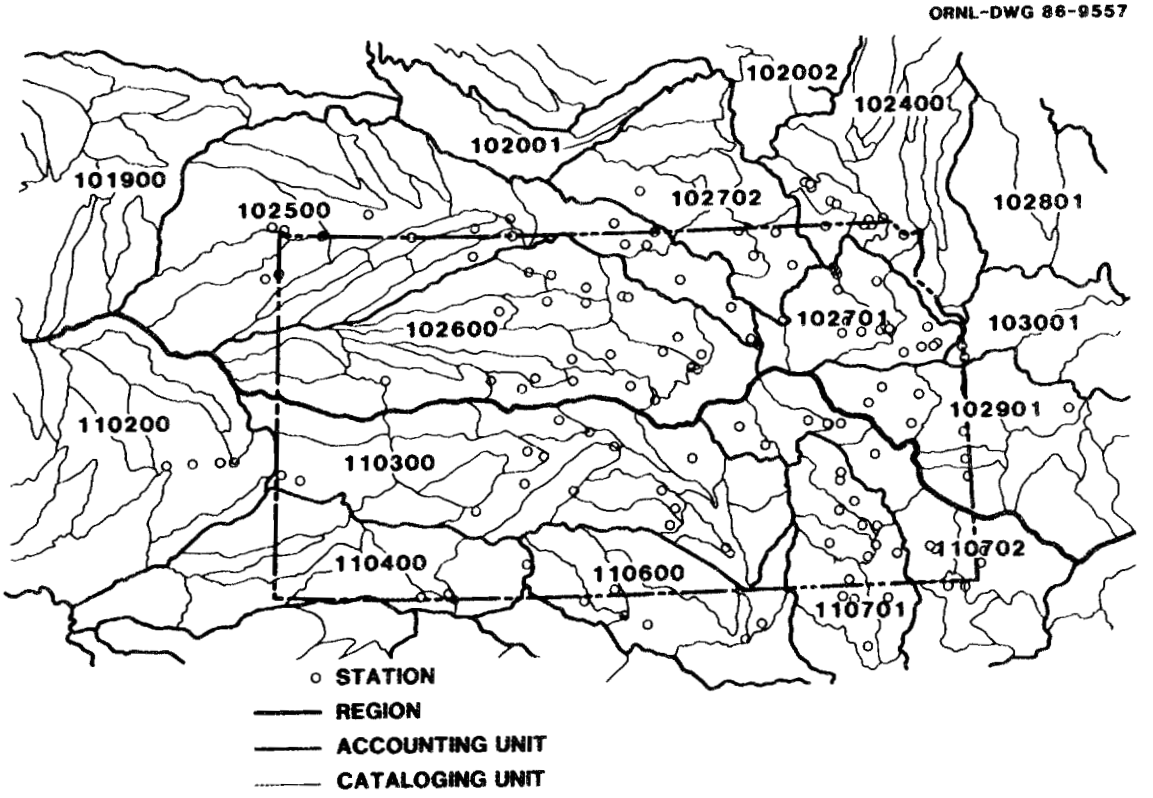

Fig. 3.1 Water quality monitoring stations used in this study, and cataloging and accounting units for Kansas.

analyses were not distributed uniformly throughout the state. Western cataloging units had few or no stations that met the criteria regarding number of observations and period of record. Because some of the large streams in industrialized areas on the Missouri River, the Kansas River, and the Arkansas River had too many NPDES dischargers, the water quality stations located on these reaches were dropped. In addition, because there are more permanent streams in the eastern part of the state, more stations are located there.

The terrestrial ecosystems of Kansas as described by Bailey (1978) and the SCS (1981) are shown in Fig. 3.2. The state is divided by Bailey (1978) into the Humid Temperate Domain in most of the state and the Dry Domain in the extreme west. The sections from east to west are Oak-Hickory-Bluestem Parkland (2511), Oak & Bluestem Parkland (2512), Bluestem Prairie (2531), Bluestem-Grama Prairie (2533), and the Grama-Buffalograss (3113). Like the Bailey (1978) classification, the divisions of major resource areas of the SCS (1981) divide the state from east to west. The three major sections are the Central Feed Grains and Livestock Region (M), the Central Great Plains Winter Wheat and Range Region (H), and the Western Great Plains Range and Irrigated Region (G). A small section of the Southwestern Prairies Cotton and Forage Region (J) also juts into southeast Kansas. The boundary between the western and central regions is located on the Colorado state line, farther west than Bailey's (1978) corresponding boundary. However, the boundaries delineating the Central Great Plains region in the east are comparable to that dividing the Tall Grass Prairie (2531 & 2533) from the Prairie Parkland (2511 & 2512) on Bailey's (1978) map.

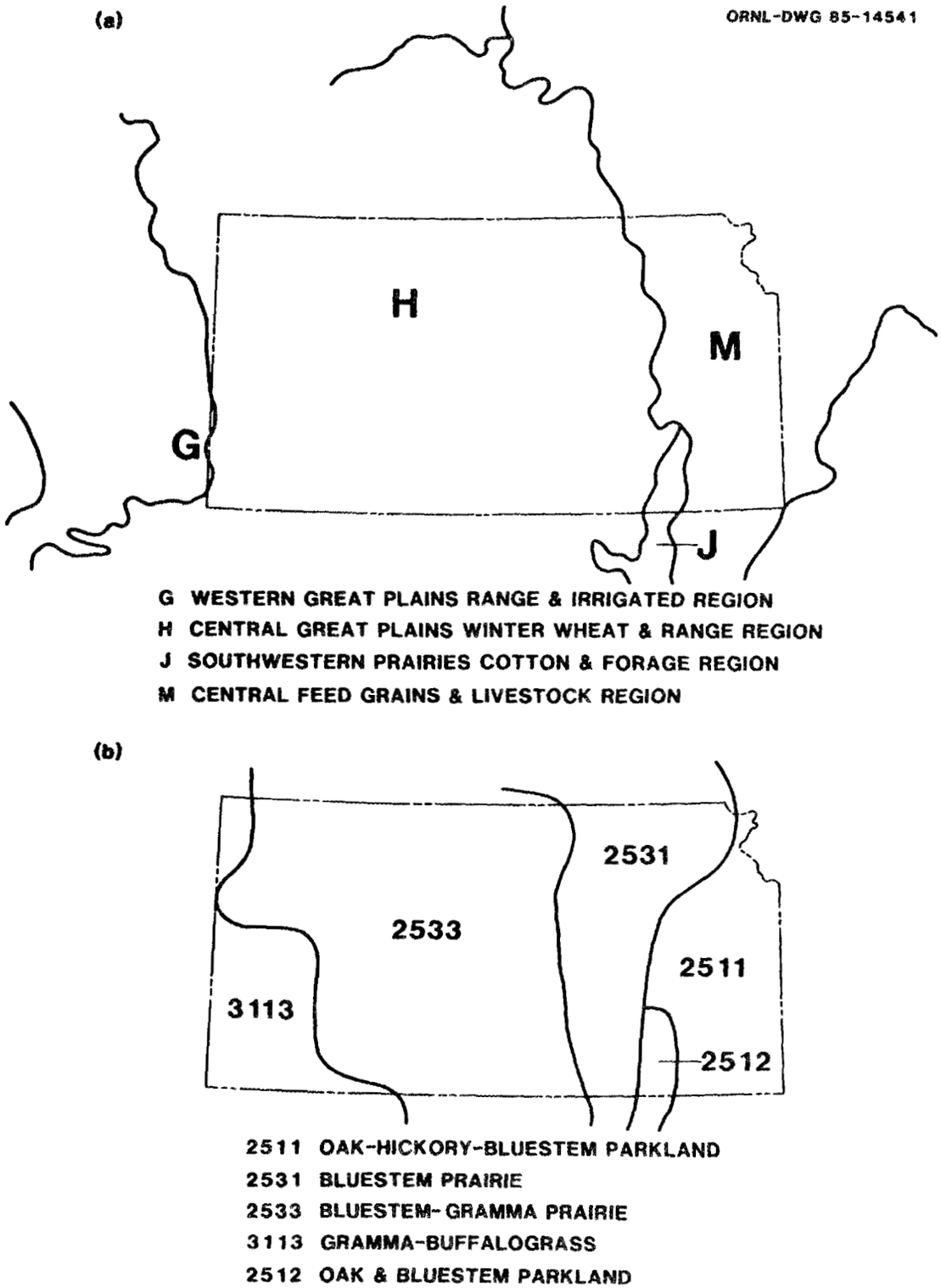

Fig. 3.2 Ecosystem classifications for Kansas: (a) Soil Conservation Service's land resource regions, and (b) Bailey's ecoregions.

The smaller divisions bear little resemblance to each other. Bailey (1983) acknowledges that the placement of boundaries is inherently subjective. These lines represent gradual changes in environmental gradients, so a line on his map could have a large uncertainty where environmental gradients do not change abruptly.

A trend of decreasing precipitation is noted from east to west, with the extreme southeastern corner of the state receiving on the average 2.5 times as much precipitation each year as the western edge of the state (USDC 1968). The amount varies widely from year to year, with an average of approximately 400 mm falling on the western border versus 1000 mm in the southeast (SCS 1981). Summer high temperatures are fairly uniform throughout the state, but winter temperatures are increasingly colder from the southeast to the northwest (USDC 1968).

There are two major geological strata that divide the state nearly in half from east to west. In the west, there are Quarternary, Upper Tertiary, and Cretaceous deposits of sands, gravels, and silts (USDOI 1970, Smith and Fisher 1970). The eastern half of the state is underlain by older limestones and shales (Smith and Fisher 1970). The soils of the state follow patterns similar to the lithological patterns. Except along the major rivers, the western soils tend to be drier than the eastern soils (USDOI 1970). Most of the Kansas soils tend to be alkaline, which results from low soil moisture and the recycling of nutrients by prairie grasses (Bailey 1978).

Most of the land in Kansas is used as cropland or grazing land, with an increase in the amount of tilled cropland from west to east (SCS 1981). Native short and tall grasses remain on poorer soils and

steeper slopes, whereas the richer, level soils are placed into production of winter wheat, corn, and other crops (SCS 1981). The eastern quarter of Kansas historically had oak-hickory forests, with additional elm-ash and cottonwood forests along major streams in the Missouri River basin, but most of these no longer exist (USDOI 1970).

Smith and Fisher (1970) describe seven groups of fishes with similar habitat requirements within a group in Kansas. Three of these groups, which are centered on eastern watersheds, have been combined into the eastern group in Table 3.1, where general descriptions of the habitats for each group are based on descriptions by Cross (1967). Cross (1970) noted a trend of decreasing fish species diversity from east to west that followed major watersheds rather than crossed watersheds. All fish species found in the western part of the state were also found in the eastern streams (Cross 1967). The big river fish group does not appear to be strongly influenced by environmental variables other than stream size. However, the other groups of fishes do show specific habitat preferences that may relate to environmental influences on water quality. The cool-water prairie fishes are found in the extreme northern and eastern streams of Kansas. The more tolerant prairie and plains group overlaps the range of the cool-water prairie fishes and extends farther south and west. The eastern group is the compilation of three drainage-basin-centered groups identified by Smith and Fisher (1970). Warm-water fish are found with the other associations of fish in eastern Kansas, but their range extends farther along the southwestern border of the state. Figure 3.3 shows the approximate zero isoclines from trend surface maps for two of the fish

Table 3.1. Distribution of fish in Kansas

Distribution[a]	Number of species	Characteristic habitat[b]
Big river	21	Large rivers or tributaries adjacent to large rivers, slow current, generally tolerant of moderate to high turbidity
Cool-water prairie and plains	6	Small, spring-fed streams with clear, cold water
Prairie and plains	15	Small streams, tolerant of warmer temperatures, higher turbidities, and intermittent flows
Warm water	21	Medium and large streams and rivers with warm waters, flowing over limestone
Eastern	23	Permanent flowing streams
Independent	21	Mixed

[a]Based on Smith and Fisher (1970).

[b]From Cross (1967).

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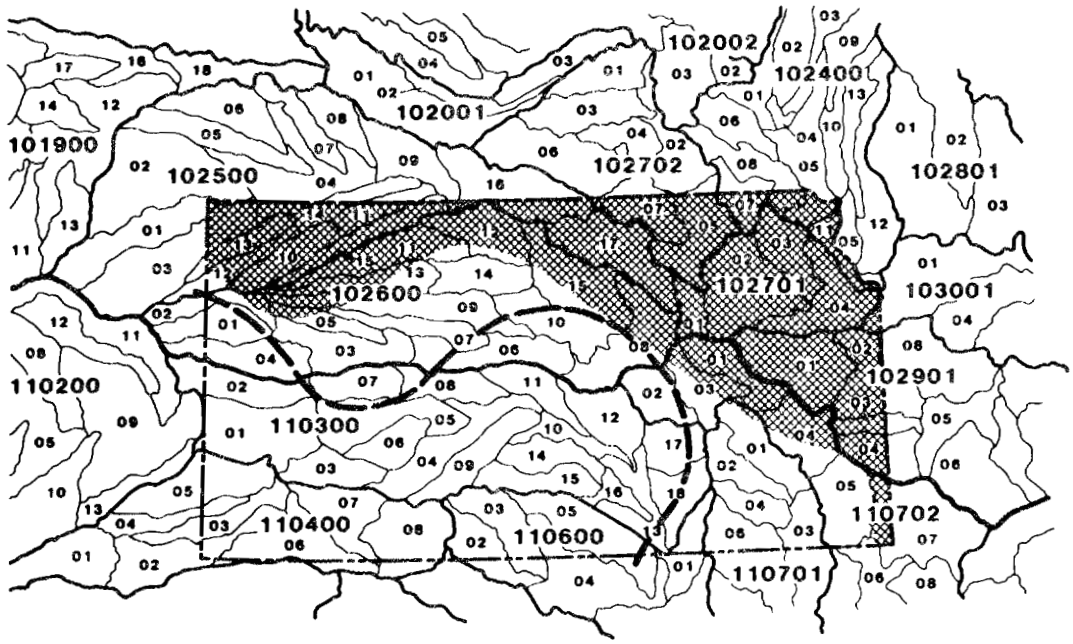
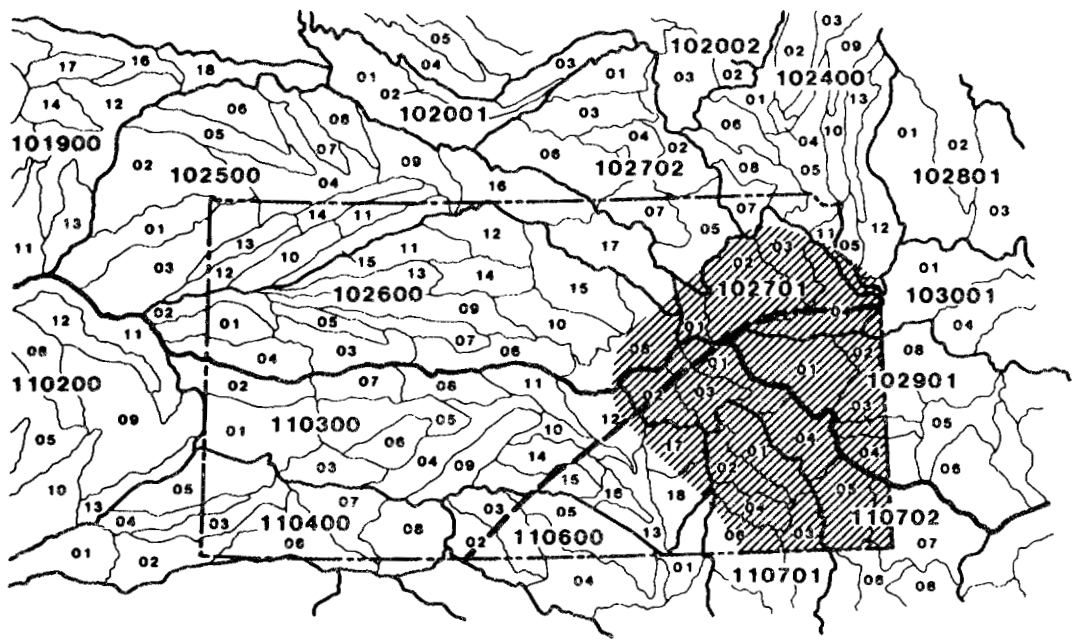


COOL WATER PRAIRIE

PRAIRIE & PLAINS (NORTH & EAST OF LINE)



EASTERN

WARM WATER (EAST OF LINE)

Fig. 3.3 Kansas fish distributions with respect to cataloging and accounting units.

groups reported by Smith and Fisher (1970). Because isoclines relate to the probability of finding the fish in these areas, they do not delineate the actual limits to the fish distributions. As a result, fish in the eastern group or cool-water prairie group are found in unshaded areas on the map but are really more likely to be found in the shaded regions.

3.2 GEORGIA

The 109 water quality stations in 30 cataloging units of Georgia (Fig. 3.4) were not evenly distributed across the state, but they were more uniformly located than those in Kansas. The primary reason for the absence of stations from some of the cataloging units was the large number of NPDES dischargers in these areas and, therefore, the removal of nearby stations for this study.

The terrestrial biotic divisions of Georgia are comparable for Bailey (1978) and the SCS (1981) (Fig. 3.5). Bailey's (1978) major ecoregion boundary divides the Hot Continental and the Subtropical divisions. These are subdivided into three provinces and four sections. The Eastern Deciduous Forest province has the Mixed Mesophytic Forest (2211) and the Appalachian Oak Forest (2214). The Outer Coastal Plain Forest province is in the central portion of the state (2320), and the Beech-Sweetgum-Magnolia-Pine-Oak Forest (2311) of the Southeastern Mixed Forest province is in the south (Bailey 1978). The corresponding map by the SCS (1981) delineates the East and Central Farming and Forest Region in the north (N), the South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region (P), and the Atlantic

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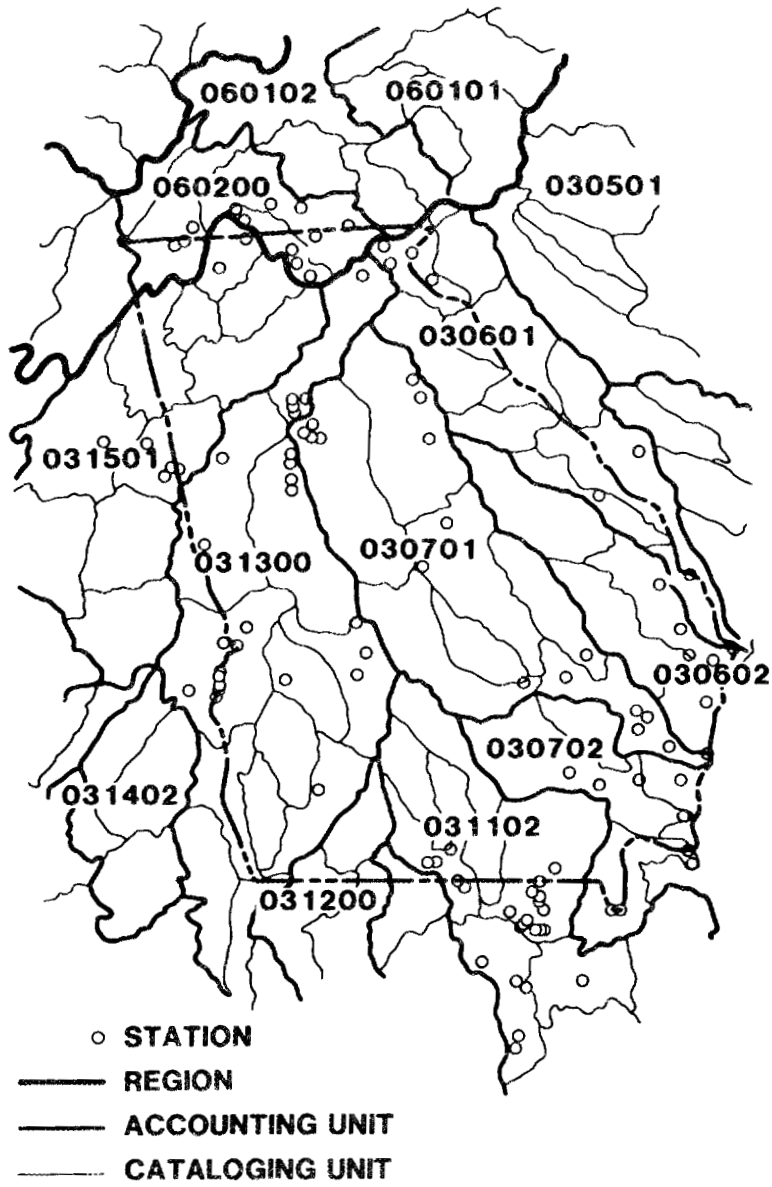
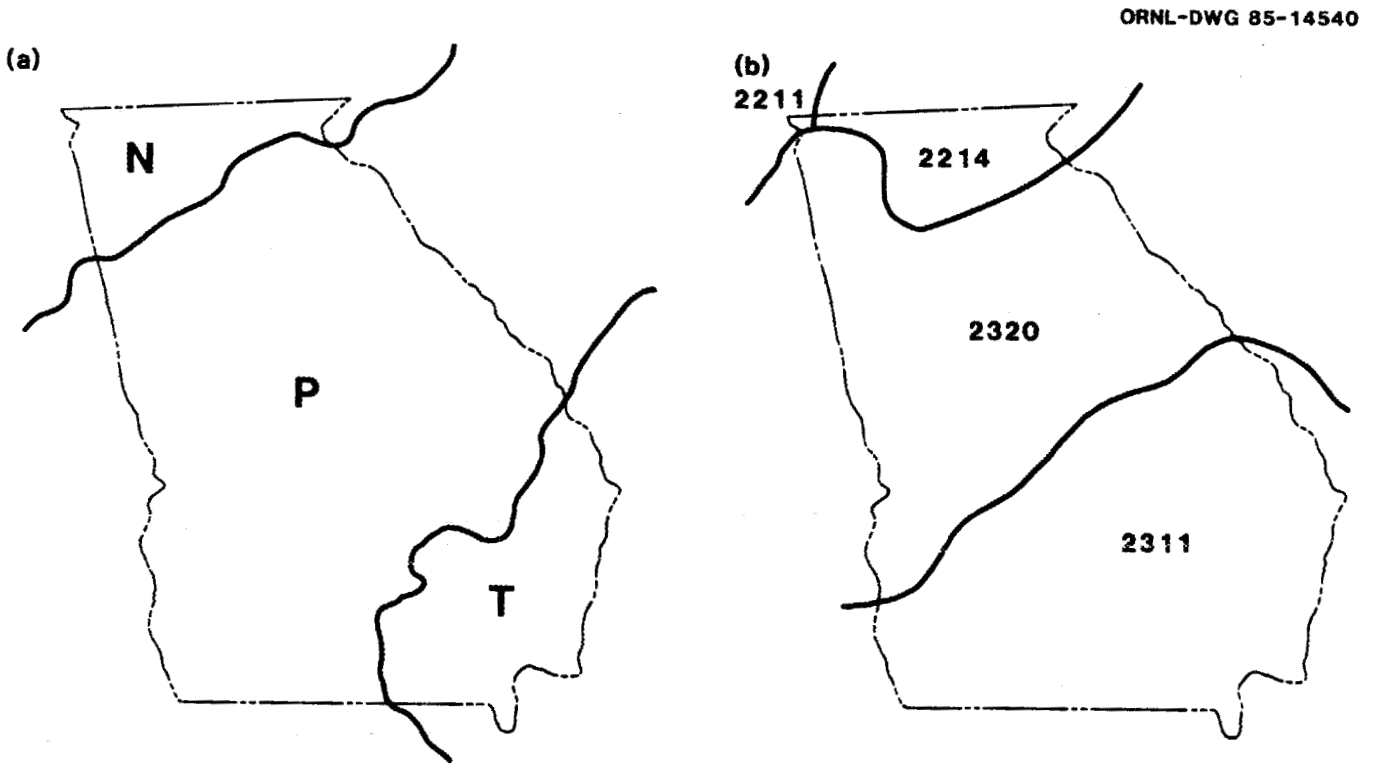


Fig. 3.4 Water quality monitoring stations used in this study, and cataloging and accounting units for Georgia.



N EAST & CENTRAL FARMING & FOREST REGION

P SOUTH ATLANTIC & GULF SLOPE CASH CROPS, FOREST, & LIVESTOCK REGION

T ATLANTIC & GULF COAST LOWLAND FOREST & CROP REGION

2211 MIXED MESOPHYTIC FOREST

2214 APPALACHIAN OAK FOREST

2320 SOUTHEASTERN MIXED FOREST

2311 BEECH-SWEETGUM-MAGNOLIA-PINE-OAK FOREST

Fig. 3.5 Ecosystem classifications for Georgia: (a) Soil Conservation Service's land resource regions, and (b) Bailey's ecoregions.

and Gulf Coast Lowland Forest and Crop Region along the coastlines (T). The central section in Bailey's (1978) system includes less of the southwestern part of Georgia and more of the northwestern part than does the corresponding section in the SCS (1981) system.

The climate of Georgia is affected by the mountains of the north and the coastal influences of the Gulf of Mexico and the Atlantic Ocean. Annual precipitation of 2032 mm is normal in the mountainous, northeastern part of the state, whereas only 1118 mm is expected in the central Savannah River valley (USDC 1968). The coastal areas also have higher precipitation than the interior coastal plains. Temperature patterns in the state are also influenced by the mountains which have cooler temperatures all year, and by the oceans which cool the coast in the summer and warm it in the winter (USDC 1968).

The lithology of the coastal plain of Georgia is undifferentiated sedimentary rocks, sands, and gravels, whereas the piedmont is underlain by mixed crystalline rocks including granite, schist, and gneiss (Pickering and Murray 1976). The extreme northeast corner of Georgia is underlain by old sedimentary rocks. Most of the state's soils are not specific to the underlying bedrock materials; they are generally warm, moist ultisols, except along the coast where the soils are generally warm, wet ultisols (USDOI 1970).

Land use in Georgia is predominantly cropland with some pasture and forest (USDC 1968). The northern region is forested, whereas central Georgia is the major crop-farming and livestock area in the state, and the southern coastal plain below the Fall Line is predominantly forested (SCS 1981). The forests of the mountains in

northern Georgia are oak-hickory changing to oak-pine then loblolly and shortleaf pine forests with a decrease in elevation (USDOI 1970). The southern forests contain long leaf and slash pines on upland soils and oak, gum, and cypress in the wet soils along streams and swamps (USDOI 1970).

The distributions of the freshwater fish of Georgia were listed by Dahlberg and Scott (1971), who did not classify the fish into groups with similar distributions or habitat requirements as Smith and Fisher (1970) did for Kansas. Therefore, such a classification was performed as part of this study. The results of the agglomerative hierarchical clustering that classified fish into unique groups are given in Table 3.2. The distribution of these groups in Fig. 3.6 indicate the area where each group of species is most likely to occur, although not exclusively. These distributions do not represent probability isoclines as in Fig. 3.3. Six groups of species were identified based upon the historical presence or absence of each fish species in 15 watersheds. The fish species within each group often exhibited similar habitat tendencies. The groups with the most uniform distributions and habitat requirements were the cool-water fishes of the mountains river systems and the lowland species that inhabit warm, sluggish backwaters of the major rivers and most streams and swamps near the coast. The fish species in the coastal and lowland group overlap the habitats and names of the lowland group but are found more often in the southeastern streams of Georgia.

Table 3.2. Distribution of freshwater fish in Georgia

Distribution[a]	Number of species	Characteristic habitat[b]
Cold-water uplands	63	Swift, clear, cool streams over coarse substrate in Tennessee River and Alabama River drainages
Upland	28	Clear, cool streams with coarse substrate above the Fall Line
Lowland	54	Slow or still streams and backwaters below the Fall Line
Coastal	9	Acidic backwaters near the coastline
Big river	17	Slow medium-sized streams to large rivers with much vegetation
Savannah River	25	Mostly in the Savannah River basin ranging from cool water upland to backwater lowland

[a]Based on checklist by Dahlberg and Scott (1971).

[b]From Lee et al. (1980).

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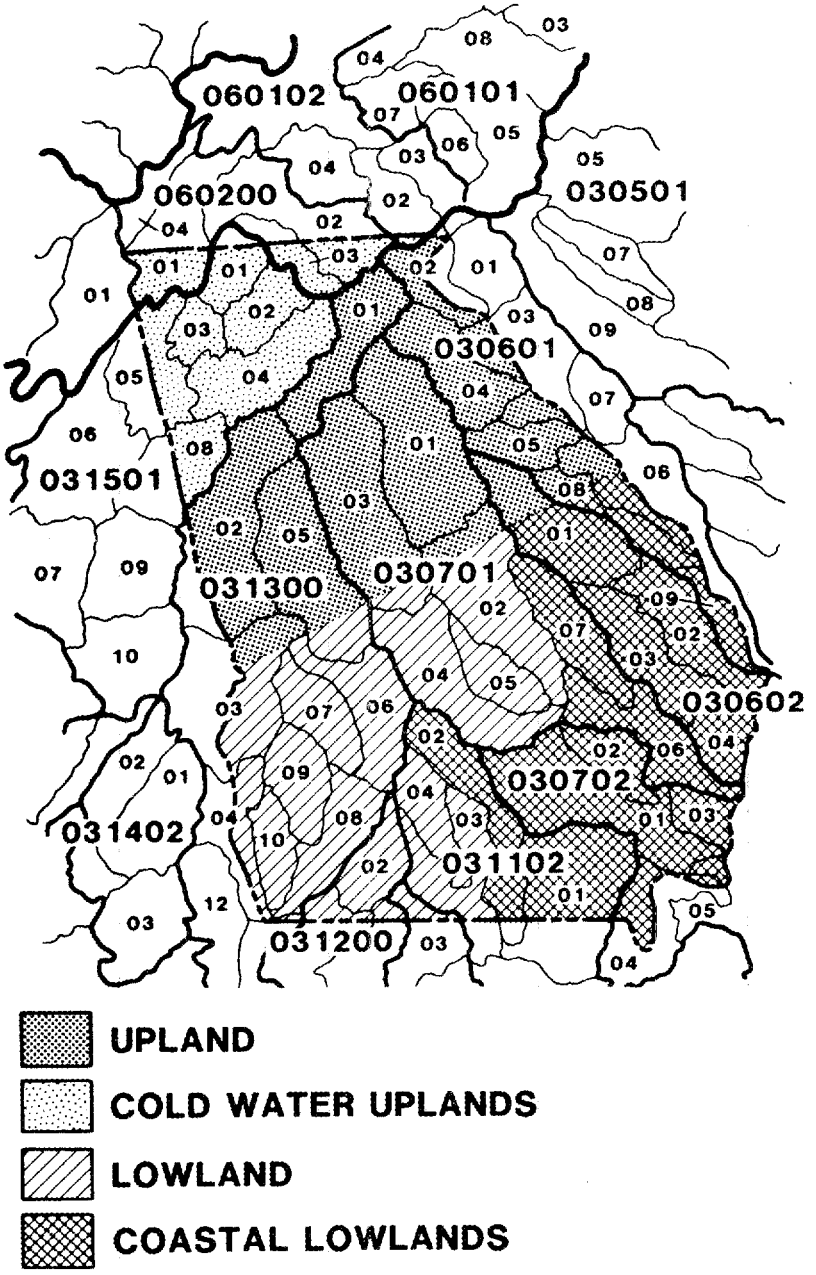

Fig. 3.6 Georgia freshwater fish distributions with respect to cataloging and accounting units.

4. RESULTS

Although the two areas studied had widely varying ecosystem types, climates, and physiographic influences, the multivariate procedures were able to detect differences in patterns of regional water quality and fish for both states. These patterns were sometimes similar to other regional ecological patterns.

4.1 KANSAS

Univariate analysis of variance procedures yielded six variables that differed significantly between classes (accounting units) for Kansas. These were the means of water temperature, pH, total alkalinity, dissolved oxygen, and conductivity, and the upper decile of turbidity. The probabilities that the ratios of between-class mean squares to within-class mean squares would be greater than the observed F ratio under the null hypothesis of no difference are given in Table 4.1. The correlations of each observed variable with the first and second canonical variables are also listed in Table 4.1. The canonical discriminant analysis is able to account for approximately 70% of the between-class variability in the first two canonical variables and to reduce the dimensionality from six variables to two. The first canonical variable accounts for approximately 50% of the between-class variation. Mean temperature, pH, and conductivity are positively associated with the first axis, while dissolved oxygen is negatively correlated with it. The second canonical variable is positively associated with mean total alkalinity, pH, dissolved oxygen,

Table 4.1. Within-class canonical correlations for Kansas water quality variables

Water quality variable	(P > F)a	Within-group canonical correlation	
		First canonical variable	Second canonical variable
Mean water temperature (°C)	<0.01	0.33	-0.54
Upper decile turbidity (FTU)[b]	<0.01	0.01	0.47
Mean conductivity (μS/cm @ 25°C)	0.03	0.15	-0.29
Mean pH	<0.01	0.55	0.34
Mean dissolved oxygen (mg/L)	0.02	-0.26	0.11
Mean total alkalinity (mg/L as $CaCO_3$)	0.01	-0.02	0.46

[a]Probability that the between-class to within-class mean square is greater than the observed F ratio under the null hypothesis of no difference.

[b]FTU = Formazin turbidity unit.

and upper decile turbidity. Temperature and conductivity are negatively associated with the second canonical variable. Therefore, the first canonical variable represents a comparison involving primarily temperature, pH, conductivity, and dissolved oxygen, whereas the second canonical variable represents a comparison of all six variables.

Figure 4.1 shows the plot of the accounting unit means for the first and second canonical variables. The approximate 95% confidence regions are drawn according to Seal (1964). The outlying 110400 and 110600 accounting units have high values for mean pH and temperature and low values for dissolved oxygen concentrations, while the 110200 accounting unit has higher dissolved oxygen concentrations, low pH, and moderate temperature values. Both the 110400 and 110600 accounting units are located along the Kansas and Oklahoma border, and the Cimarron River flows from one accounting unit to the other. The three accounting units at the top of the graph (102400, 102500, 102702) are located in northern Kansas along the Nebraska state line. These watersheds were characterized by low water temperature and high turbidity and alkalinity. Figure 4.2 shows the value of the first two canonical discriminant scores for each of the individual cataloging units. One can obtain an indication of the degree of internal variability within an accounting unit from this figure.

The CANDISC procedure also calculates the Mahalanobis distances between each pair of classes (Table 4.2). These distances are a measurement of the statistical "distance" between these points in the canonical-variate space. Thus, a large distance (or low probability)

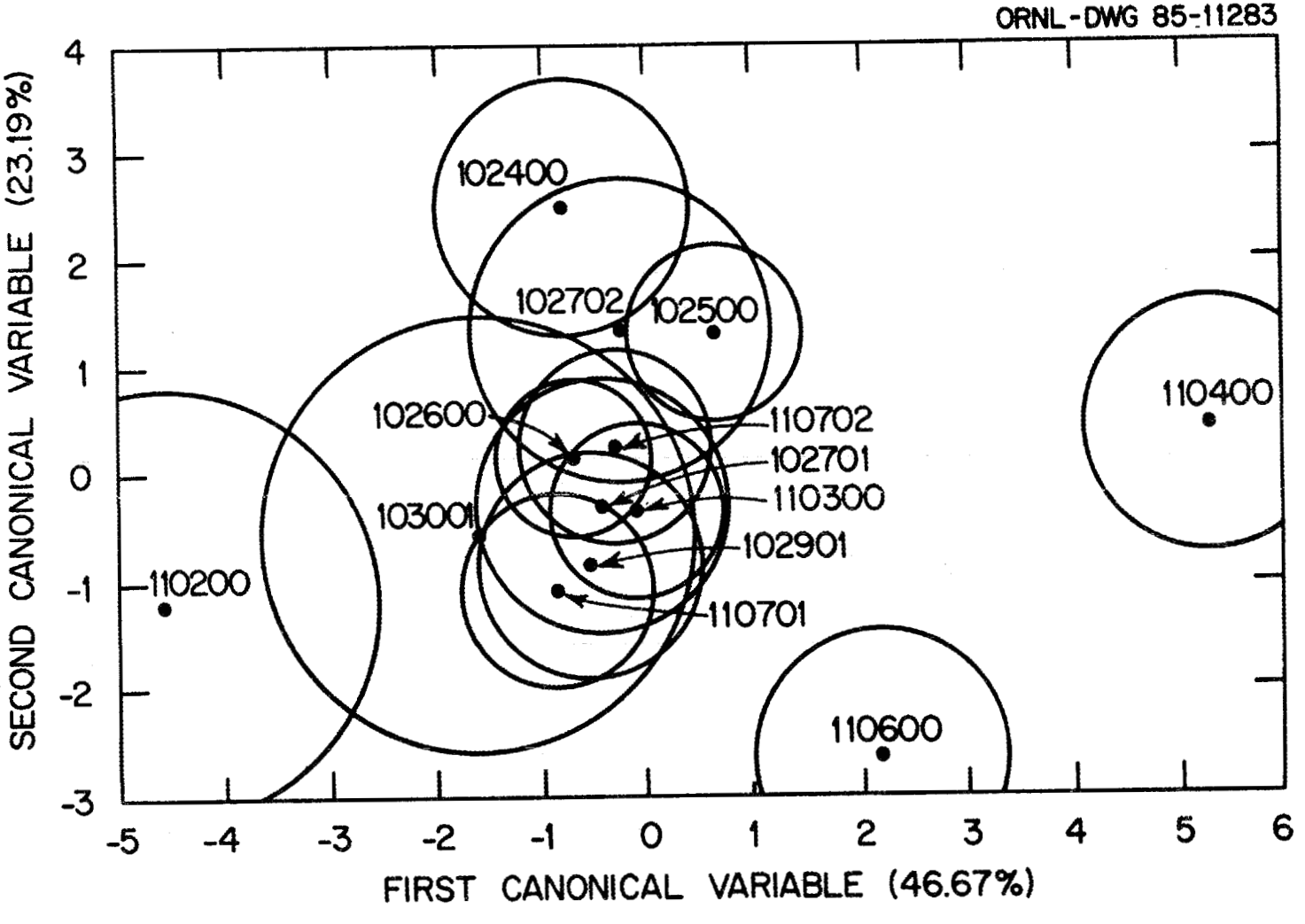

Fig. 4.1 Means of the first and second canonical variable developed for accounting units in Kansas.

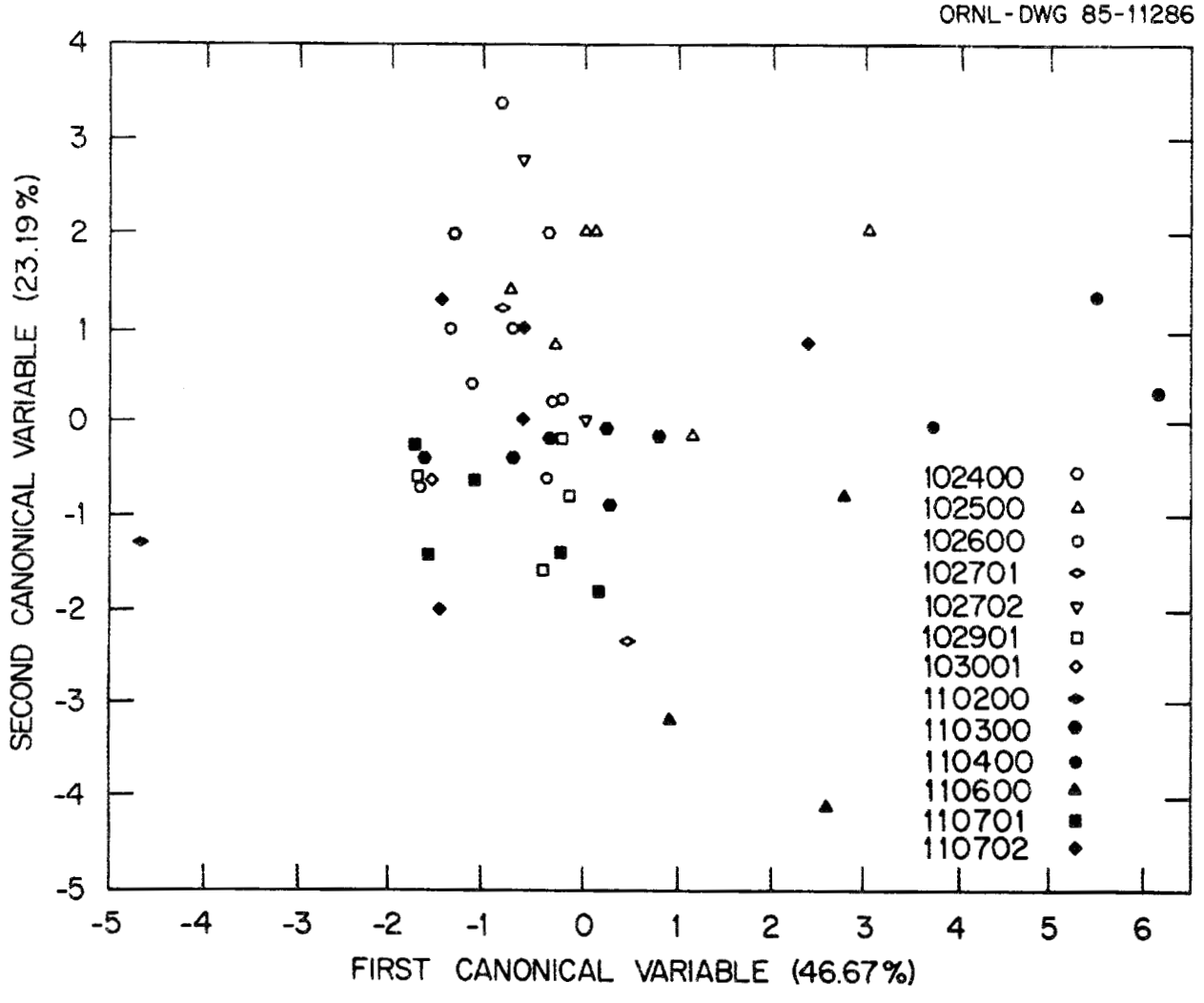

Fig. 4.2 Values of first and second canonical variables from Kansas cataloging units.

Table 4.2. Mahalanobis distances between classes for Kansas accounting units[a]

Accounting unit	Number of cataloging units	102400	102500	102600	102701	102702	102901	103001	110200	110300	110400	110600	110701	110702
102400	3	--	2.85	2.94	3.32	2.55	4.07	3.43	6.37	3.26	6.52	6.00	3.90	2.92
102500	6	*[b]	--	2.04	2.21	4.16	3.34	3.25	6.65	2.35	4.81	4.73	3.29	2.14
102600	8	*	0.03	--	1.55	3.97	2.55	1.85	5.14	1.09	6.01	4.32	2.13	1.46
102701	3	0.05	0.64	0.94	--	3.65	2.43	1.69	5.33	1.49	5.84	3.87	1.54	1.66
102702	2	0.61	0.31	0.50	0.20	--	4.59	3.93	6.77	3.59	6.42	5.24	3.92	3.59
102901	4	*	0.04	0.31	0.10	*	--	1.67	6.60	2.79	6.31	4.44	1.54	1.98
103001	1	0.86	0.97	0.99	0.99	0.62	0.99	--	5.07	2.21	6.99	4.66	1.11	1.82
110200	1	0.22	0.50	0.86	0.43	0.07	0.31	0.12	--	5.35	10.48	7.33	5.69	6.21
110300	6	*	0.05	0.85	0.29	*	*	0.01	*	--	5.46	3.39	2.03	1.67
110400	3	*	0.01	*	*	*	*	*	*	*	--	4.62	6.39	5.66
110600	3	*	0.01	0.07	0.01	*	0.01	*	*	0.16	*	--	3.95	4.41
110701	5	*	0.01	0.31	0.40	*	0.47	0.62	*	0.26	*	*	--	1.63
110702	5	*	0.21	0.73	0.31	*	0.19	0.10	*	0.50	*	*	0.47	--

[a]Upper triangular section gives Mahalanobis distance values, and lower triangular section gives the probabilities for testing the null hypothesis that Mahalanobis distance equals 0.

[b]* = <0.01.

indicates that the pair of accounting units differ significantly, based on the observed water quality variables. The number of cataloging units in each accounting unit and the within-class mean squares affect these distances. Thus, the 103001 accounting unit, which has only one cataloging unit in Kansas, cannot be separated from most of the other accounting units. However, many of the accounting units do show statistically significant differences. Conversely, those accounting units with several cataloging units that were not found to differ significantly ($P > 0.50$) are assumed to have similar water quality characteristics.

The discriminant analysis gives an estimate of the number of cataloging units that are misclassified into the wrong accounting unit (Table 4.3). By default, 103001 and 110200 are misclassified because they each contained only one cataloging unit in the analysis. Except for those two, only four of the remaining eleven accounting units have 50% or more of their cataloging units misclassified. In contrast, only one or zero misclassifications are reported for seven of the accounting units. This exercise shows that many accounting units in Kansas are homogeneous enough, with respect to water quality, to allow the development of a function that can correctly classify a cataloging unit into its larger-scale watershed. These results are corroborated by the plot in Fig. 4.2; accounting units that are homogeneous also have cataloging units that tend to plot within two units on the canonical plot.

A simple quartile ranking of the values for each variable by cataloging unit produces some observable patterns (Figs. 4.3 through 4.5).

Table 4.3. Discriminant analysis misclassifications for Kansas cataloging units

Accounting unit	Percent misclassified
102400	0 (0/3)[a]
102500	33 (2/6)
102600	50 (4/8)
102701	67 (2/3)
102702	50 (1/2)
102901	25 (1/4)
103001[b]	100 (1/1)
110200[b]	100 (1/1)
110300	33 (2/6)
110400	0 (0/3)
110600	0 (0/3)
110701	40 (2/5)
110702	60 (3/5)

[a]Numbers in parentheses are the number of cataloging units misclassified over the total number of cataloging units tested.

[b]Misclassified because these accounting units contain only one cataloging unit.

Figure 4.3 shows that the lowest mean water temperatures were generally in the northeast, whereas the highest were generally in the south along the Oklahoma border. As one would expect, a north to south trend is apparent. The upper decile turbidities are usually lowest in the southeast half of the state, while the highest values are generally reported throughout the rest of the state (Fig. 4.3). Specific conductance appears to show a general east to west trend of increasing values (Fig. 4.4). This corresponds to an increasing concentration of dissolved solids in the streams. The mean pH does not appear to show a broad geographical trend, instead, it exhibits a pattern of high and low pH's in a checkerboard-like configuration (Fig. 4.4). Even in this pattern there tends to be a uniformly high or low pH within a watershed. The western cataloging units have generally lower dissolved oxygen concentrations than units in the central part of the state; however, units in the southeastern corner also have low concentrations (Fig. 4.5). The geographical trend for total alkalinity is similar to that for turbidity, with the lowest values observed in the southeast (Fig. 4.5). However, the highest alkalinities are more consistently in the north than are the high turbidities.

4.2 GEORGIA

A univariate analysis of variance yielded five significant variables for classifying water quality in Georgia. These are the means of water temperature, dissolved oxygen, and turbidity, and the upper deciles of total phosphorus and conductivity (Table 4.4). The first and second canonical variables account for almost 90% of the

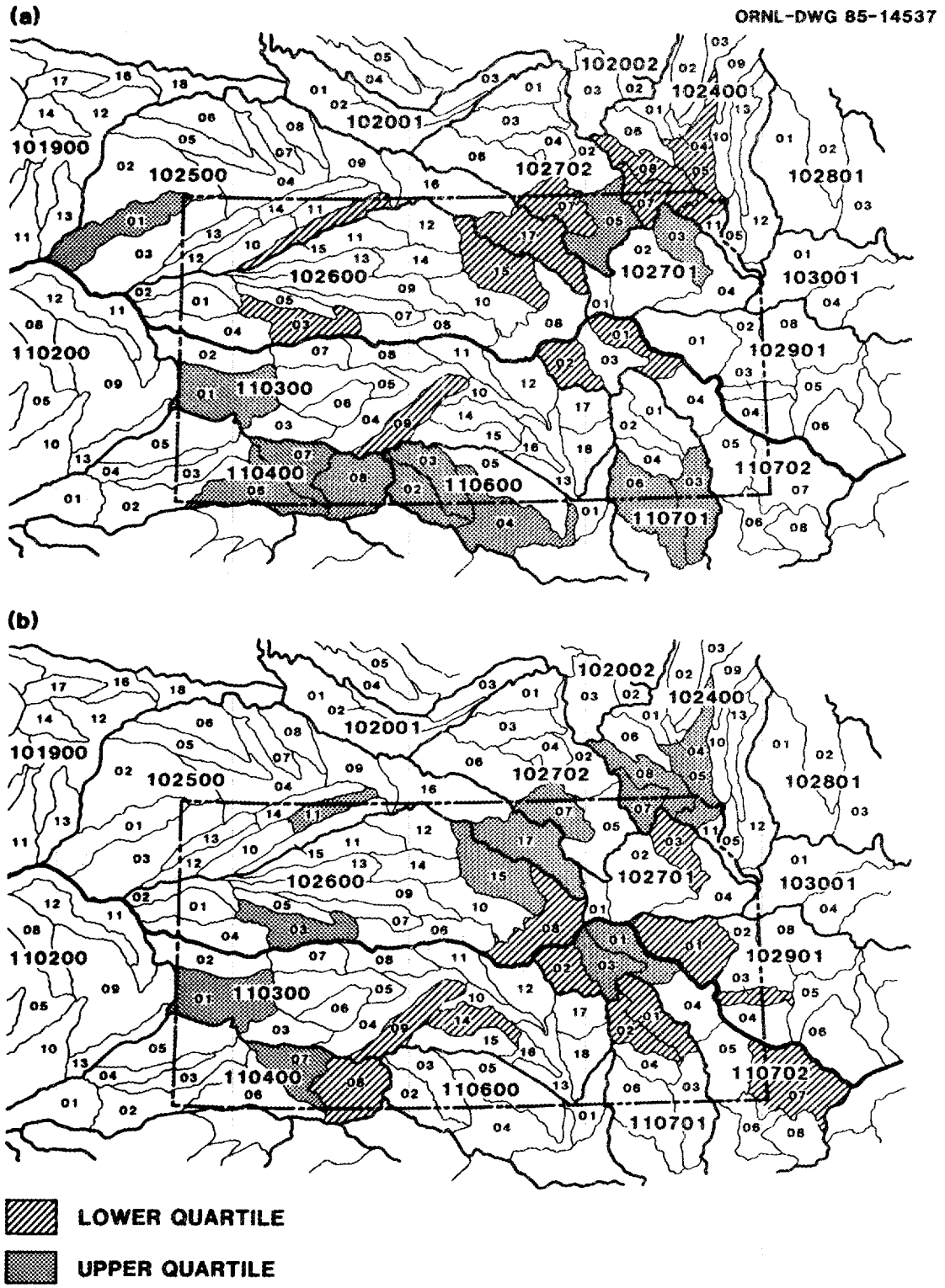

Fig. 4.3 Quartile ranks of Kansas water quality variables: (a) mean water temperature, and (b) upper decile for turbidity.

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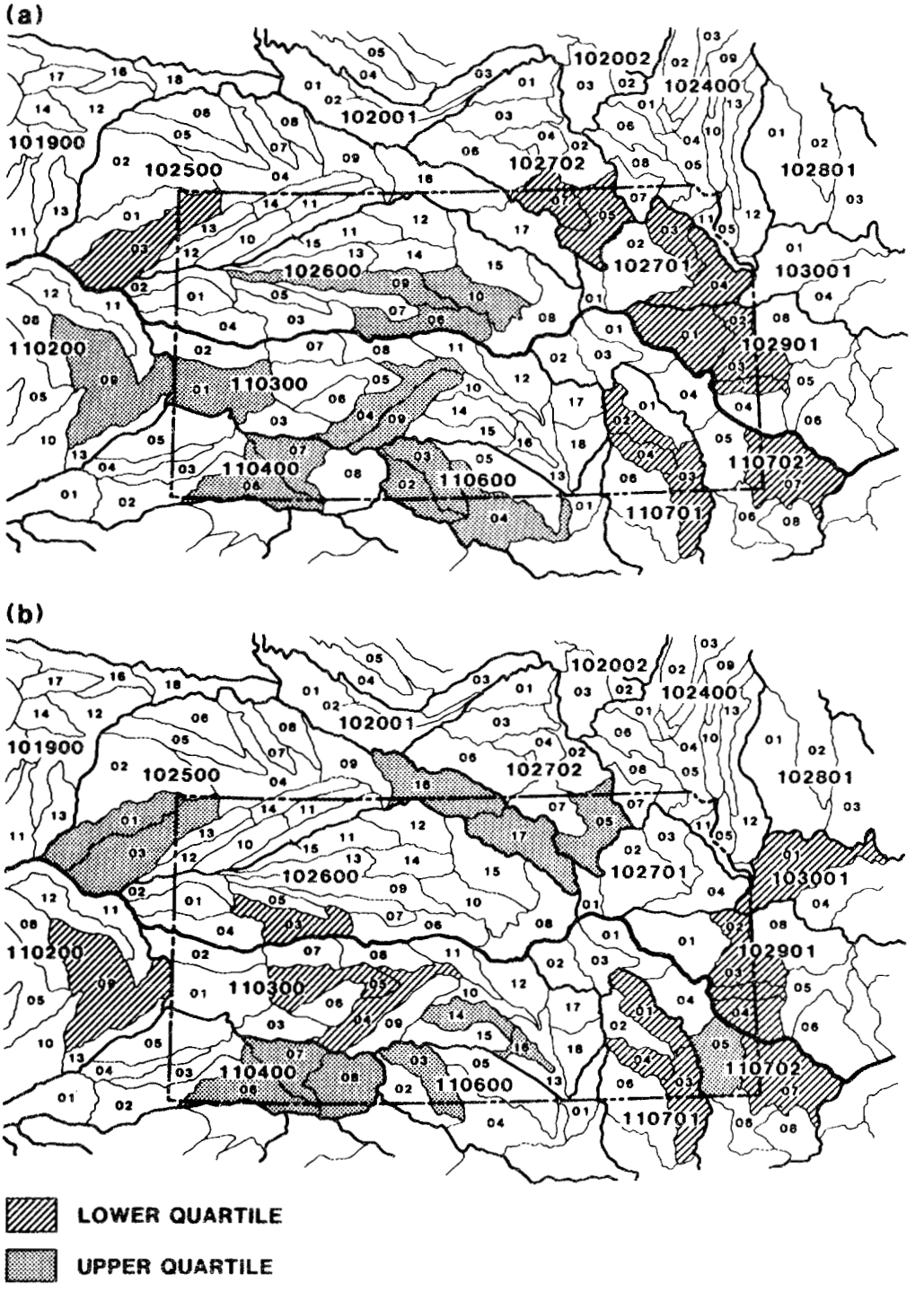

Fig. 4.4 Quartile ranks of Kansas water quality variables: (a) specific conductance, and (b) pH.

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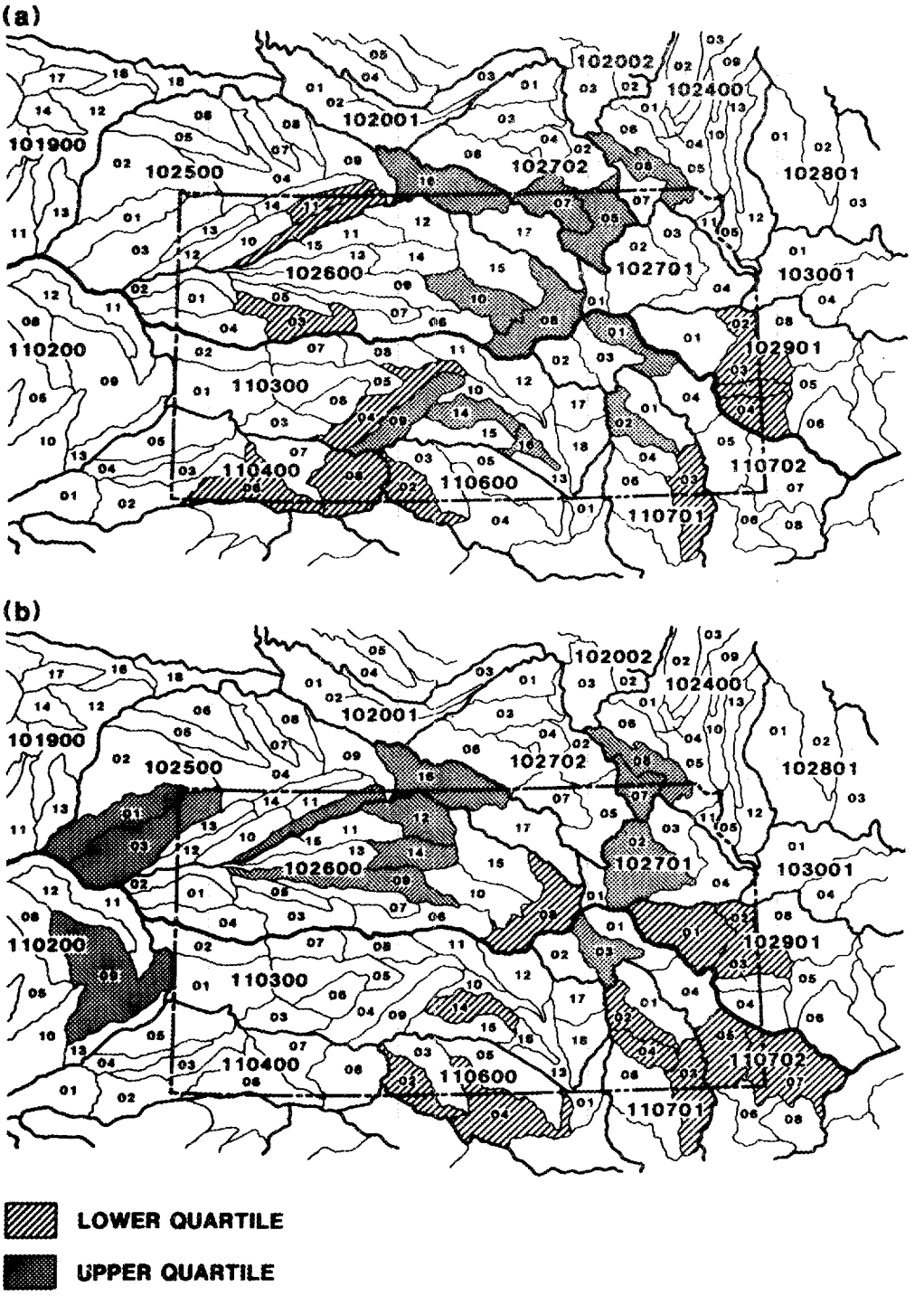

Fig. 4.5 Quartile ranks of Kansas water quality variables: (a) dissolved oxygen, and (b) total alkalinity.

Table 4.4. Within-class canonical correlations for Georgia water quality variables

Water quality variable	$P > F$[a]	Within-class canonical correlation: First canonical variable	Within-class canonical correlation: Second canonical variable
Upper decile total phosphorus (mg/L as P)	0.02	-0.03	0.48
Mean water temperature (°C)	<0.01	0.27	0.70
Upper decile conductivity (μS/cm @ 25°C)	<0.01	0.76	0.05
Mean dissolved oxygen (mg/L)	<.01	-0.27	-0.58
Mean turbidity (JTU)[b]	0.03	-0.21	0.10

[a]Probability that the between-class to within-class mean square is greater than the observed F ratio under the null hypothesis of no difference.

[b]JTU = Jackson turbidity unit.

between-class variability, with the first canonical variate accounting for almost 75% of the between-class variance. Conductivity and temperature are positively associated with the first axis, whereas dissolved oxygen and turbidity are negatively correlated with it (Table 4.4). The second canonical axis is correlated positively with water temperature and phosphorus and negatively with dissolved oxygen. These three variables are the major influence in the second canonical variable, whereas conductivity dominates the first canonical variable.

The plot of the accounting unit means and their approximate 95% confidence regions for the first two canonical variables shows two accounting units widely separated from the remainder on the first axis (Fig. 4.6). Both of these watersheds exhibit high water temperatures and conductivities. The second canonical axis separates one accounting unit from the rest on each end of the scale. At the top of the plot, 031102 has high temperatures and low dissolved oxygen, whereas the 060200 unit has the opposite conditions. The plot of the individual cataloging units (Fig. 4.7) shows similar trends of internal variability as the Kansas cataloging units did. Interestingly, several of the outlying accounting units have one or more cataloging units that do not group much differently than the majority of the other cataloging units. For example, 06020001 is located in the midst of several other cataloging units, but the other two cataloging units in that accounting unit are distinctly separated. The same pattern is observed with the 030602 accounting unit.

Table 4.5 lists the Mahalanobis distances for pairs of accounting units and the probabilities for testing the null hypothesis that these

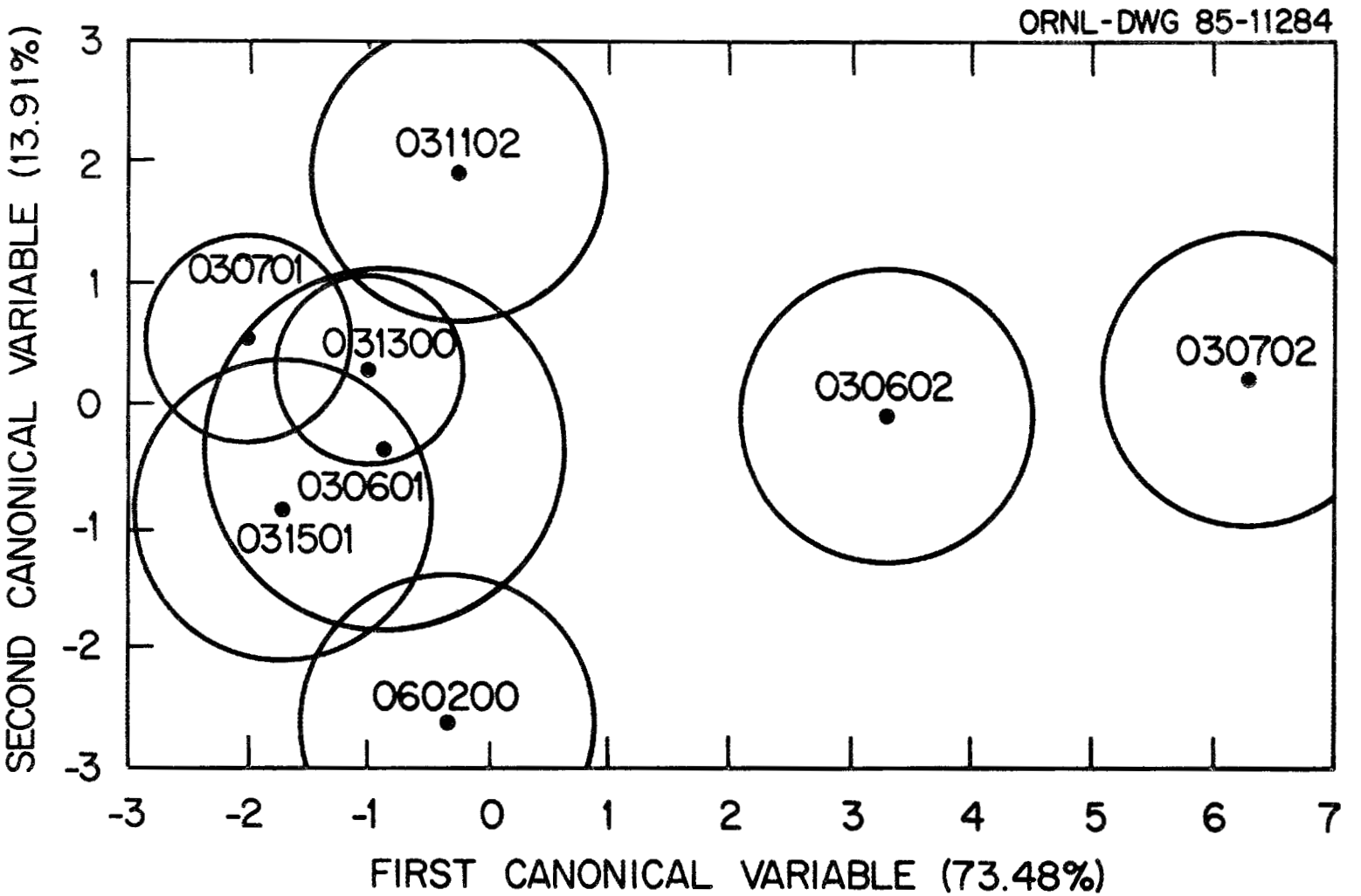

Fig. 4.6 Means of the first and second canonical variables developed for accounting units in Georgia.

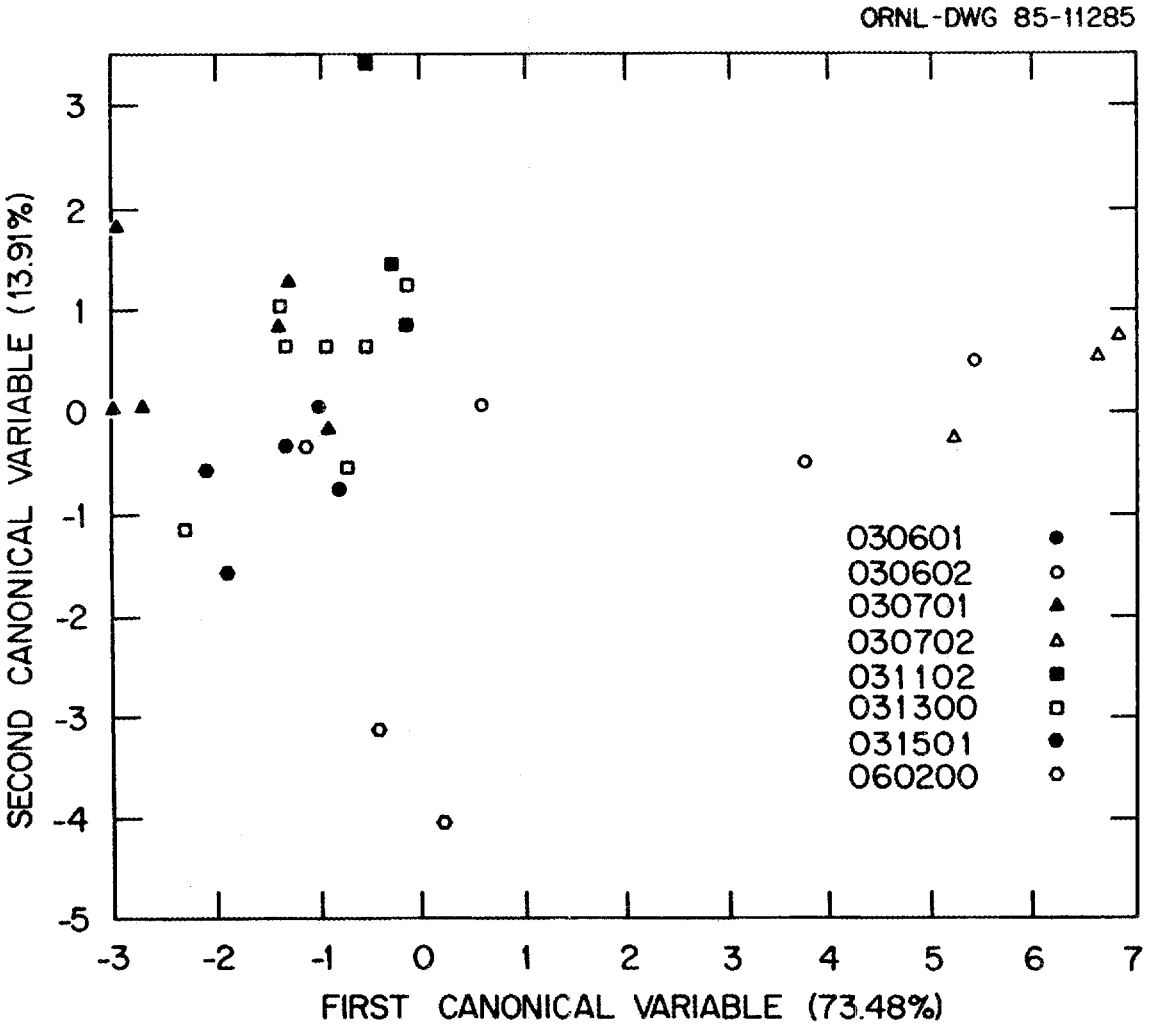

Fig. 4.7 Values of first and second canonical variables from Georgia cataloging units.

Table 4.5. Mahalanobis distances between classes for Georgia accounting units[a]

Accounting unit	Number of cataloging units	030601	030602	030701	030702	031102	031300	031501	060200
030601	2	--	4.29	2.11	7.23	3.40	1.61	1.73	2.85
030602	3	*[b]	--	5.36	2.98	4.76	4.35	5.05	4.68
030701	6	0.03	*	--	8.27	3.88	1.74	1.66	4.22
030702	3	*	0.10	*	-	7.20	7.28	8.01	7.35
031102	3	0.02	*	0.07	*	--	2.87	3.99	4.60
031300	7	0.09	*	0.15	*	*	--	1.75	3.20
031501	3	0.51	*	0.81	*	0.01	0.81	--	2.73
060200	3	0.08	*	0.04	*	*	0.24	0.16	--

[a]Upper triangular section gives Mahalanobis distance values, and lower triangular section gives the probabilities for testing the null hypothesis that Mahalanobis distance equals 0.

[b]* = $P < 0.01$.

distances are zero. The 031501 accounting unit exhibits a low degree of dissimilarity to most of the other accounting units, especially to 030701 and 031300. The Mahalanobis distances and Fig. 4.6 both indicate that the 030602 and 030702 accounting units are significantly different from all other accounting units.

The discriminant analysis of the Georgia water quality data produces the misclassification results in Table 4.6. Two of the eight accounting units have greater than 50% of their cataloging units misclassified into the wrong accounting unit. In comparison, five of the accounting units have only one or zero misclassified cataloging units. As in Kansas, the discriminant functions for Georgia that perform well at classifying cataloging units into the correct accounting unit correspond to the cataloging units that plot within two units on the canonical plot (Fig. 4.7).

The geographical patterns in water quality are shown in the maps in Figs. 4.8 through 4.10. The first shows the trend in total phosphorus concentration, which is highest in the central piedmont region and in the 031102 accounting unit (Fig. 4.8). The areas with low phosphorus concentrations are in the Appalachian streams and in some of the coastal rivers. A north to south trend of increasing water temperature (Fig. 4.8) and decreasing dissolved oxygen concentration (Fig. 4.9) is also observed. Upper decile conductivities are highest along the coastline, but the lowest values are not grouped in an easily definable pattern (Fig. 4.9). Turbidities are greatest in the piedmont and lower along the coast and in the mountains, just like total phosphorus concentrations (Fig. 4.10).

Table 4.6. Discriminant analysis misclassifications for Georgia cataloging units

Accounting unit	Percent misclassified
030601	0 (0/2)[a]
030602	67 (2/3)
030701	33 (2/6)
030702	0 (0/3)
031102	33 (1/3)
031300	57 (4/7)
031501	0 (0/3)
060200	33 (1/3)

[a]Numbers in parentheses are the number of cataloging units misclassified over the total number of cataloging units tested.

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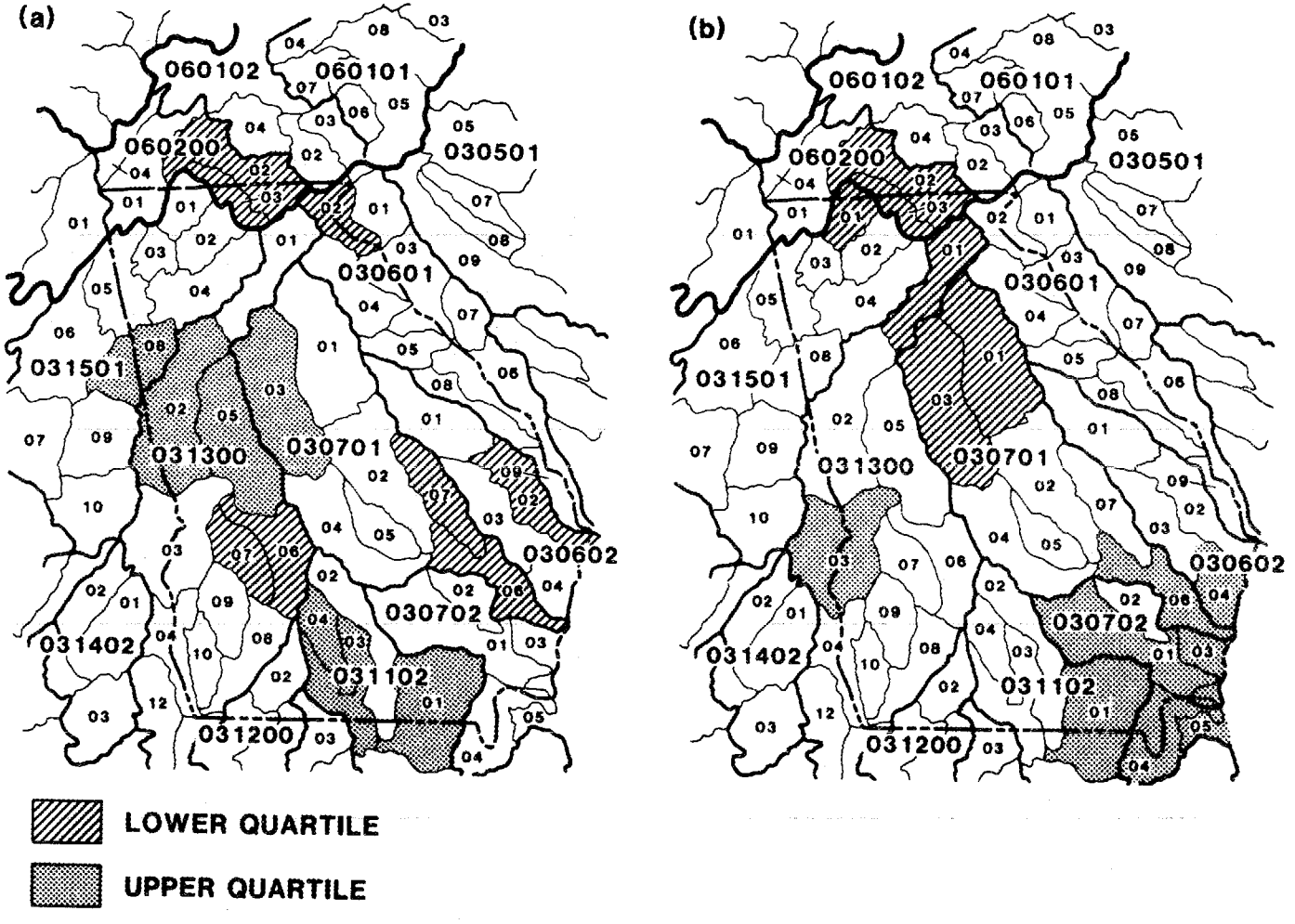

Fig. 4.8 Quartile ranks of Georgia water quality variables: (a) total phosphorus, and (b) water temperature.

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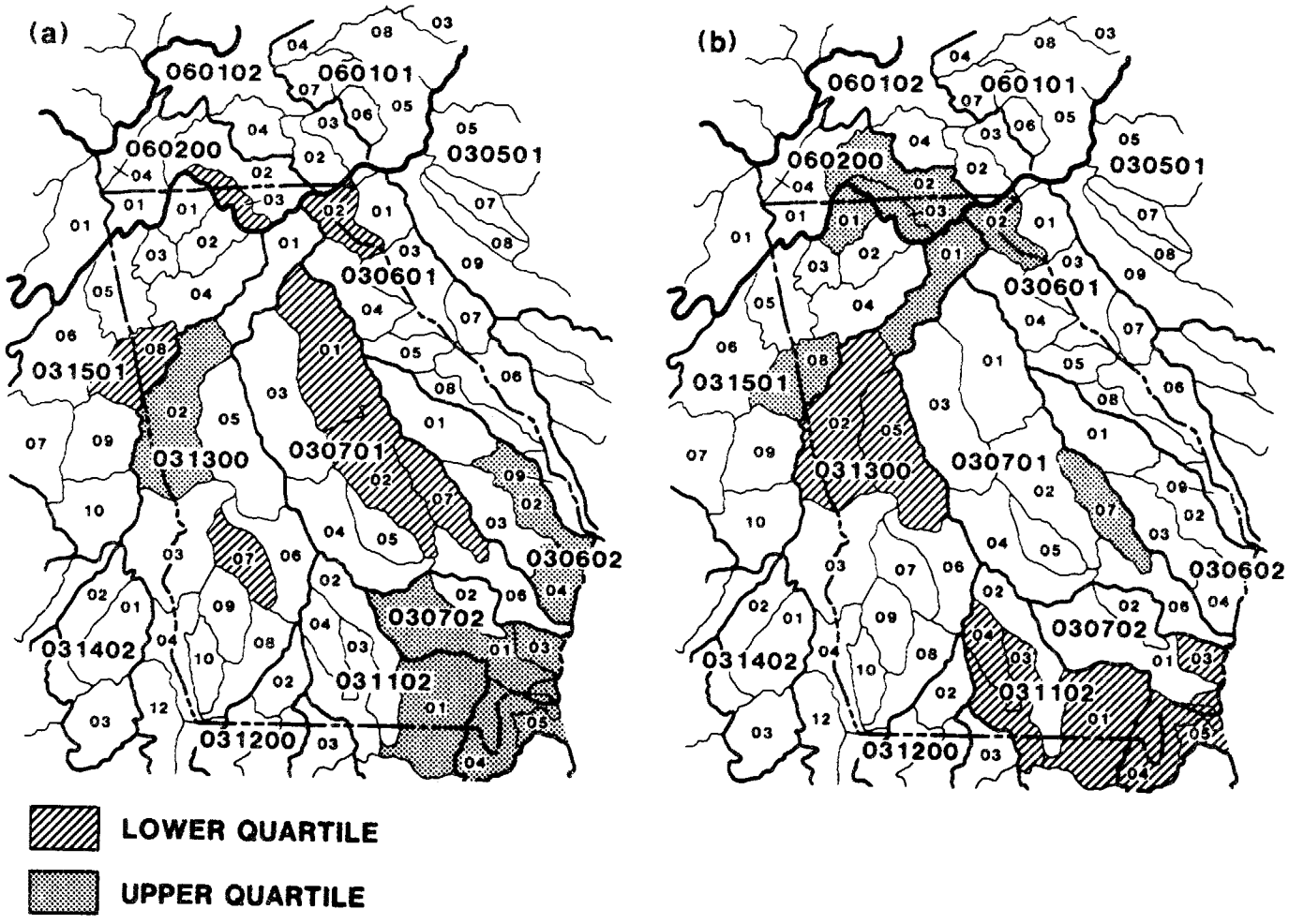

Fig. 4.9 Quartile ranks of Georgia water quality variables: (a) upper decile for conductivity, and (b) dissolved oxygen.

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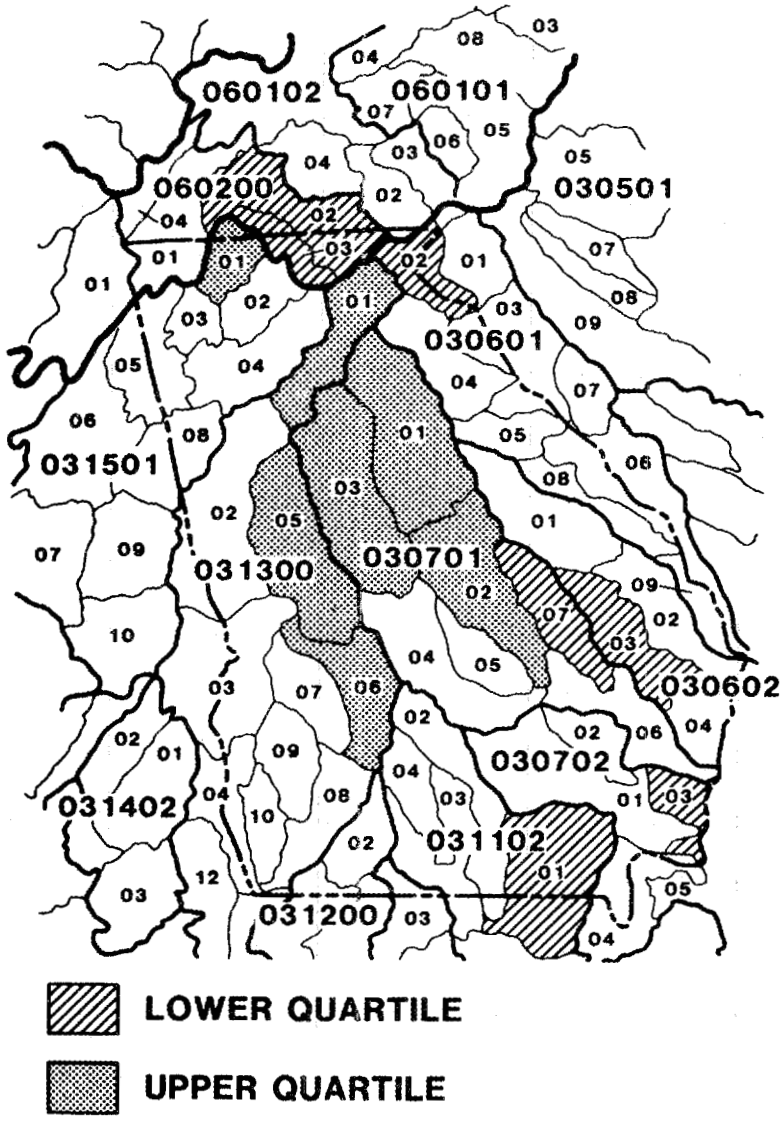

Fig. 4.10 Quartile rank of turbidity in Georgia.

5. DISCUSSION

The multivariate statistical methods used to analyze regional water quality patterns for Kansas are also appropriate for Georgia. Because these two states have greatly different physiographic and climatic regimes, this method can be considered to be generally applicable for evaluating regional patterns in water quality.

5.1 TERRESTRIAL ECOSYSTEM-WATER QUALITY RELATIONSHIPS

The six variables selected by the univariate procedure for the state of Kansas and the five selected for Georgia are all indicators of climatic, geologic, vegetational, and anthropogenic influences. Water temperature follows a north to south trend in both Kansas and Georgia (Figs. 4.3 and 4.8) as would be expected from climatic data. In addition, the high-elevation areas in both states tend to have cooler stream temperatures. The trend of increasing temperature from east to west in Kansas as described by Cross (1970) is not detected by these analyses, and water temperature patterns do not correlate with terrestrial ecosystem patterns delineated by Bailey (1978) or the SCS (1981). This is probably due to the lack of water quality monitoring stations in western Kansas that measure all the variables of interest. In southeast Kansas and northern Georgia, the cold water in streams at higher elevations is attributable to several factors including groundwater input, a higher degree of shading by vegetation, and a lack of anthropogenic warming influences. In Georgia, the temperature trend is similar to both ecosystem classification systems (Fig. 3.5).

Regional patterns of dissolved oxygen concentration (Figs. 4.5 and 4.9) are similar to water temperature patterns in both states. The high values for dissolved oxygen are generally associated with cooler waters and vice versa. However, in Kansas the western cataloging units that have low temperatures do not have high dissolved oxygen concentrations. This may result from the flatter terrain in western Kansas which does not provide the reaeration capacity that the hilly terrain in eastern Kansas does. In Georgia, the regions of higher temperatures are often swampy, so there is a compounding effect on the dissolved oxygen concentrations from the oxygen-demanding organic sediments and the high temperatures. The terrestrial classifications by Bailey (1978) are approximately the same geographic area as the patterns observed for dissolved oxygen in Kansas. Low concentrations are found in the 2511 and 2533 sections and high concentrations in the 2531 section. In Georgia, both terrestrial classification systems have boundaries that are similar to those for dissolved oxygen concentrations in the watersheds.

Turbidity was measured using both the Jackson and Formazin turbidity unit (JTU and FTU) scales, which are not mathematically related, so all turbidity data were not available for simultaneous analysis in either state. However, for both Kansas and Georgia, the analysis of each type of turbidity separately did show similar geographical patterns within each state. Patterns of high turbidity (Figs. 4.3 and 4.10) appear to be related to the areas with the greatest amount of agricultural land use (SCS 1981). Low turbidities in both states are generally associated with less human influence in

the watershed. The western part of Kansas historically had the highest observed turbidities because of sparse vegetation and dry, loose soils, but it now appears that the influence of plowing in the eastern part of the state also increases turbidity in the streams. The northeast corner of Kansas, which drains the Nebraska farmlands along the Missouri River, has the highest turbidities. In Georgia, the high turbidities are in the central piedmont where agricultural activities are the dominant land-use activity. This area also has high total phosphorus concentrations in the streams (Fig. 4.8) and high ammonia and nitrogen concentrations, indicating that agriculture is probably the major influence on water quality there. Likewise, the areas with low turbidities also have generally low nutrient levels in streams. High nutrient concentrations in Kansas are less correlated with turbidity levels than are those in Georgia, but both patterns are similar. In Kansas, the turbidity levels did not correlate with areas on either of the resource classification maps; however, the geographic patterns for turbidity in Georgia were similar to those in these classification systems. Total phosphorus concentrations do not appear to correlate with the regions on either of these maps.

The conditions that influence the specific conductance of streams in Georgia and Kansas are probably different. In Kansas, the east to west trend in conductivity is probably associated with a similar trend in the lithology. In contrast, the highest conductivities in Georgia are reported in coastal tributaries where saltwater intrusion and atmospheric deposition of salts greatly increase the dissolved ion concentrations in streams. Furthermore, areas with low conductivities

do not appear to be grouped in any particular pattern, suggesting that many factors may influence conductivity in the inland streams. These factors may include the highly variable bedrock materials, land use, and industrial discharges (although an attempt was made to reduce the influence of point-source discharges in these analyses). The similarity between the ecosystem maps and conductivity patterns in Kansas is limited to the region of very low conductivity in eastern Kansas which corresponds to a division on each of the maps in Fig. 3.2. The high conductivities of Georgia's coastal areas also are associated with a single division on the resource classification maps, while the remainder of the state does not have conductivities related to individual divisions.

Total alkalinity and pH are used in the analysis for Kansas but not in the one for Georgia. Alkalinities increase from the southeast to the northwest and are probably related to soil and climate relationships rather than to underlying geologic material. The presence of limestone outcrops and streambeds in southeastern Kansas would have suggested that alkalinities should be high in this region, not the lowest observed. However, the calcification processes occurring in the drier western soils may be a significant contributor to the total alkalinity of the western streams and may result in higher observed values. The regional patterns of pH are more sporadic than those of alkalinity and appear to be uniformly high or low within specific reaches of an accounting unit. For example, in the 110300 accounting unit, the 04 and 05 cataloging units have low pH streams, whereas the 14 and 16 cataloging units, separated from the two previous

cataloging units, have high pH streams. The pH of the streams in Kansas does not appear to be strongly associated with any one environmental factor. Although the pH pattern appears sporadic, it is similar to the boundaries of Bailey's (1978) ecoregion sections (Fig. 3.2). Alkalinity does not show any correlation to either terrestrial ecosystem classification system.

The cataloging and accounting units clustered together because of their similar water quality characteristics can be separated into two types of groups. The first type has only a few members that are distinctly separated from the majority of the remaining cataloging units or accounting units. These have extremely high or low values for several of the water quality variables and, as a result, have high values for one or more of the canonical variables. In Kansas, the accounting units of 102400, 102500, and 102702 are clustered in this type of arrangement (Fig. 4.1). Likewise, the cataloging units of 110400 and 110600 are separated from the other cataloging units (Figs. 4.1 and 4.2). In Georgia, the coastal cataloging units of 030602 and 030702 are also tightly clustered (Figs. 4.6 and 4.7). These groups probably represent "real" associations of adjacent watersheds with very similar water quality characteristics. The second type, which contains the majority of the accounting and cataloging units, has large clusters near the (0,0) point on the canonical axes that contain watersheds with moderate values for most of the water quality variables. These watersheds do not have distinctively different water quality characteristics that would separate them and are, therefore, similar to many other watersheds.

Some aspects of the regional water quality analysis are associated with patterns on the terrestrial ecosystem classification systems and others are not. Several of the single water quality variables in Kansas and Georgia exhibit patterns similar to the resource classification maps. Likewise, the patterns of accounting units and cataloging units sometimes approximate the boundaries of the terrestrial ecosystems (Figs. 3.2 and 3.5). The Kansas accounting units clustered together by the statistical analyses do not have boundaries that are geographically similar to the ecosystem boundaries. The watersheds are not clustered in groups from east to west like the divisions on these maps. The Georgia accounting units, however, exhibit geographic patterns similar to those in the resource maps. The northern region, which corresponds to 'N' (Fig. 3.5a) and '2214' (Fig. 3.5b), contains only 060200 in its entirety. The coastal region includes 030602 and 030702. This area is approximately the same as 'T' and '2311' in Fig. 3.5. Bailey (1978) also includes 031102 in this group but the SCS (1981) includes only a portion of it. The remaining accounting units have a small overlap with part of the northern or coastal regions, but the majority of the watersheds fall in the central region. This region contains the 030601, 030701, 031300, and 031501 accounting units. Three similar groups of watersheds were identified by the canonical discriminant analysis (Fig. 4.4 and Table 4.5). To analyze these patterns on a finer scale the patterns of cataloging units must be observed.

The boundaries of the terrestrial ecosystems depicted in Figs. 3.2 and 3.5 often intersect accounting unit boundaries. As a result, the

cataloging units of the same accounting unit but in different ecosystem divisions should be less similar to each other than to other cataloging units in the same ecosystem division. This pattern is not observed in Kansas just as the accounting unit patterns are not observed. In Georgia, however, the cataloging units do appear to segregate by terrestrial ecosystem divisions. The 03060102, 03130001, and 03150101 cataloging units are the closest cataloging units to those in the 060200 accounting unit (Fig. 4.5). These are all cataloging units that drain the mountains along the Tennessee, Georgia, and South Carolina state lines. The 03110201 cataloging unit is removed from the others in its accounting unit like the SCS (1981) map predicts.

5.2 WATER QUALITY-FISH DISTRIBUTION RELATIONSHIPS

Regional fish distributions may be explained largely by environmental variables, such as water quality, when zoogeographical limitations to dispersal are relatively minor. The previous assumption appears to have been met for Kansas (Cross 1967, 1970; Smith and Fisher 1970). Kansas is drained primarily by the Missouri and Arkansas rivers both of which empty into the Mississippi River within a relatively short distance, thus allowing easy fish dispersal (Cross 1967). However, for Georgia the only published checklist of distributions did not comment on the primary factors affecting fish distributions (Dahlberg and Scott 1971). Georgia drains into the Atlantic Ocean, the Gulf of Mexico, and the Tennessee River. The freshwater fish that are intolerant of saltwater are prevented from dispersing to nonconnecting watersheds by the natural barriers of the Atlantic Ocean and the

Gulf of Mexico. As a result, zoogeography probably plays a more important role in the distribution of fish in Georgia than it does in Kansas.

Similarities exist between fish distributions and the regional water quality patterns detected for both states, although zoogeography may also influence such distributions. In Kansas, the permanency of streams, the water temperature, and the clarity of the water appear to be the major factors affecting the fish distributions (Cross 1967). The cool-water prairie and plains fishes (Table 3.1 and Fig. 3.3) are generally found in the northern and extreme eastern streams. This distribution is similar to that observed for cold water temperatures (Fig. 4.3). The prairie and plains fishes that can tolerate higher temperatures, turbidities, and stream intermittency are found farther south and west than the cool-water species. The prairie and plains fish still tend to avoid the warmer waters of the southwestern corner of the state, which also have some of the lowest dissolved oxygen concentrations and highest conductivities. The warm-water species prefer the warmer streams in eastern Kansas where flow is permanent (Smith and Fisher 1970). This area also has generally low conductivities, and pH values are only slightly above neutral. In addition, alkalinities are lower there. The eastern group of fishes range from warm to cold streams with variable levels in turbidity. The total alkalinity, pH, and conductivity for this area are all among the lowest reported for Kansas, while dissolved oxygen concentrations are moderate. The big river fish are influenced more by the physical size of the stream than by the water quality characteristics of the watershed, just as Ross (1963) suggested. The distributions of fishes

in the independent group are not especially associated with any of the factors affecting the other fish distributions. This group is a collection of species "leftover" from the statistical analysis of environmental factors affecting distributions (Smith and Fisher 1970).

In Georgia, there are two groups of cold-water fishes and lowland fishes, based on their historic range limitations; however, on the basis of similar habitat preferences they are combined for this analysis. The two groups of cold-water fish are found primarily in the Alabama River and Tennessee River drainages (Fig. 3.6). This area of the state has the highest dissolved oxygen values, moderate to low conductivity and total phosphorus, and the coldest water temperatures (Figs. 4.8 through 4.10). The upland group of fish represents those species above the Fall Line that prefer moderate to cool water temperatures. This is the agricultural region in the state so nutrient concentrations and turbidity levels are high in the streams. The lowland group of fish inhabit slower streams and backwaters located below the Fall Line. These streams are generally warmer than the upland streams and have moderate levels of dissolved oxygen, phosphorus, turbidity, and conductivity. The coastal species are found in the streams with the highest conductivities and warmest waters (Figs. 4.8 and 4.9). The streams tend to be less turbid there, and dissolved oxygen concentrations are moderate to low. The nature of the species checklist by Dahlberg and Scott (1971) resulted in the Savannah River group containing fish with habitat preferences ranging from cold-water mountain streams to sluggish coastal backwaters. Subsequently, no generalizations can be made about this group. In

Georgia, as in Kansas, the big river species are found throughout the state and are associated with the larger streams more than with the water quality.

5.3 ANALYSIS OF ASSUMPTIONS

One of the objectives of this study was to evaluate regional ecological patterns using existing data. This process involves the use of many assumptions. Perhaps the most important assumptions involved the use, validity, and appropriateness of the data. The water quality data were collected by various state and federal agencies with different sampling frequencies. It was assumed that the methodologies employed did not produce any differences in the values reported. Data were checked for unreasonable values, but the data were assumed to be accurate because standard procedures are required by these agencies for the various water quality analyses. The water quality data for 1978 through 1982 were used and assumed to represent normal conditions over the 5-year period. In addition, it was assumed that no major water works projects, land developments, or pollutant discharges changed the natural water quality within the 5-year period. Finally, it was assumed that these current water quality characteristics could be extrapolated back to reflect the water quality conditions present when the fish distribution and land-use data were collected. The latter assumption is the one most likely to be violated and is probably the most sensitive in the analysis. However, this is an assumption that cannot be avoided in most regional assessments because of the initial cost of new data acquisition.

In the statistical analysis, several assumptions also had to be made. The SAS multivariate statistical procedures drop all stations from the analysis that had missing values for one or more of the variables. As a result, a tradeoff arose between maximizing the amount of data retained and maintaining the finest possible spatial scale of data for the maximum number of water quality variables. Most stations would have been deleted from the analysis if stations were not aggregated by cataloging unit; so the resolution of the data was sacrificed so that more data could be used. It was also assumed that the values obtained represented average conditions for the entire watershed. This assumption may also have a relatively high probability of being false and affecting the interpretation of the results, but was unavoidable with the existing data. Knowledge of the homogeneity of watershed characteristics (e.g., soil, land cover, geology) for a cataloging unit would allow one to judge the validity of aggregating water quality data in this manner.

5.4 APPLICATIONS

The procedure developed in this study for evaluation of regional water quality patterns has potential applications for regional studies. Using data from the STORET system, patterns of regional water quality for individual variables can be revealed that agree with the literature or common knowledge (i.e., water temperatures are cooler in the northern United States than in the southern United States). Multivariate statistical techniques can help one identify areas with a combination of extreme values for various water quality variables, but

probably cannot determine well-defined patterns for areas with moderate values for the same variables. The expansion and refinement of these procedures may lead to a better way to manage lands or permit discharges based on a knowledge of the regional water quality. Additionally, aquatic ecologists interested in the distributions of fish, insects, algae, etc., may be able to characterize the water quality conditions associated with various population levels of an organism. They may subsequently use this information to predict the presence or abundance of an organism in areas with inadequate data or to select alternatives when a proposed management action would alter the water quality. The methods used in this study may need to be modified for use in other projects, but the potential value in regional studies has been demonstrated.

6. CONCLUSIONS

The use of multivariate statistical tests has been shown to reveal the existence of patterns in regional water quality in Georgia and, to a lesser extent, in Kansas. These patterns are consistent with those reported in the literature and thus show that STORET data were adequate for the purpose of this study. This study also indicates that combined data sets collected by different individuals for different purposes can be used with these methods as a useful procedure for characterizing large-scale water quality patterns.

In Kansas, several trends were noted for individual water quality variables, but the analyses failed to adequately classify watersheds into groups with similar water quality, based on all six variables. This may have been the result of a relatively uniform environment throughout the state which does not produce major regional differences in water quality. The watersheds did not produce patterns very similar to the regional terrestrial ecosystem divisions. Likewise, the fish distributions in Kansas did not appear to correspond to the patterns suggested by the multivariate statistical procedures used on the water quality data, although they did show a correlation with some individual water quality variables. In a fairly homogeneous state such as Kansas, the identification of landscape patterns using both watershed characteristics and water quality would better delineate regional differences.

The patterns in Georgia water quality were much more distinct than those in Kansas. The analyses aggregated watersheds into groups with

similar water quality characteristics, using five variables. The patterns that resulted from the multivariate analyses were similar to those suggested by Bailey (1978) and the SCS (1981) for terrestrial ecosystems. The water quality patterns were similar to the ecosystem patterns at the scales of both the accounting and the cataloging units. The distributions of fish in the state also appeared to be associated with the patterns in water quality. A greater range in the environmental factors affecting terrestrial and aquatic ecosystems may have assisted in revealing these patterns in regional water quality and their correlation with terrestrial ecosystem patterns and fish distributions.

The significance of this study rests on its potential applications for regional and national studies involving the characterization of water quality. It shows that water quality patterns can be evaluated with observational data that is patchy in both time and space. The ability to confirm patterns reported in the literature suggests that the conclusions are valid, that the methods are useful, and that the data are adequate though not ideal. Analytical approaches of this type should aid regional ecologists, planners, or managers who need water quality information but cannot afford the time and expense of collecting new data. This is especially relevant to government agencies, such as the U.S. Forest Service, that are required to prepare assessments of various natural resources from a local to a national scale.

The methods applied in the study were able to reveal patterns when water quality characteristics were substantially different between

accounting units. Perhaps some fine tuning will enable the detection of less distinct patterns. Even at the current level of detection, the procedures could be useful in recognizing regions with severely degraded, pristine, or unique water quality characteristics. Perhaps most importantly this work indicates that the detection of spatial patterns having ecological significance should be possible by performing multivariate analyses on water quality data and watershed characteristics data such as land cover, soil type, and runoff potential.

Many questions were raised as this project progressed, and some of these may develop into future research projects. A logical follow-up to these analyses would be to hierarchically classify the water quality monitoring stations by the terrestrial ecosystem divisions to determine if the patterns still hold and whether more or less of the variation is explained in the two-dimensional space. To test Ross' (1963) hypothesis that terrestrial biomes affect streams inversely proportional to their size, the physical variables flow and stream level could be added to the analysis. Another area which promises some interesting implications for policy and resource management is looking at the water quality of a region before and after some quantifiable land-use change by comparing a tract of forest with clear-cut patches to an uncut tract of forest. The results of this study and future research projects related to it should be useful for management of the nation's natural resources.

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