A QUANTITATIVE ASSESSMENT OF TEXAS' WETLANDS AND SURFACE WATER SYSTEMS

by

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ABSTRACT

A quantitative assessment of Texas' Wetlands and Surface Water Systems. (April 1983)

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Twelve distinct and homogeneous wetland regions were defined for Texas by considering water availability and substrate characteristics. Regions were subsampled and measured by wetland classes, and the average values extrapolated for the regional total and these totals summed for the state totals. The Texas estimated wetland resource consists of 22,896 km^2 of perennial ponds, 1,181 km^2 of intermittent ponds, 74,500 km of perennial streams, 790,318 km of intermittent streams, 489 km^2 of marsh, and 700 km^2 of wooded marsh. Eastern regions and the Coastal region are most rich in all of these wetland types.

ACKNOWLEDGEMENTS

I wish to express my sincerest gratitude to my major professor, Dr. F. S. Hendricks. Without his valuable guidance and assistance, this study would not have been possible.

I would like to acknowledge the Undergraduate Fellows Program for giving me this opportunity, and the Texas A&M Wildlife Department for supplying any necessary materials and equipment.

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INTRODUCTION

As populations increase in Texas, demands upon our water resources become more severe. Water is not always present in the quantity, quality or proximity desired (Texas Water Development Board 1982). Furthermore, there are conflicts between the various possible water uses and needs, such as industrial cooling, versus municipal drinking, versus fisheries. Obviously the water resources cannot be utilized for all purposes together as many are mutually exclusive. Also, when consumptive use is involved, the supply is further limited.

In order to derive the maximum possible benefit from our waters, we must not only study the alternative use, and potential values, but also define the types and amounts of surface water resource itself. There is an immediate need to study and quantify the sum of the state's water resource. Once the resource is known, the state can then better manage its water supply.

I propose to quantify the wetlands and water systems of Texas by:

1) identifying wetland types to be considered
2) redefining homogeneous biotic regions of Texas which reflect wetland variation
3) obtaining averaged values of wetland quantities for each region by measuring subsamples
4) calculating the total wetland quantity of Texas by summing the extrapolated regional totals.

This thesis follows the format and style of the Journal of Wildlife Management.

LITERATURE REVIEW

History

When Texas was first settled, the state seemed vast and with an unlimited supply of resources (Texas Water Development Board 1977). As people continued to immigrate, demands on the resources became greater and the supplies more limited. Consequently, the industrial and municipal demands Texans placed upon the environment and water resources grew and became critical. In addition to man's urban and industrial needs of water, Texas water resources are required for agriculture, wildlife, recreation, and other commercial enterprises such as commercial fisheries and aquaculture.

The Federal Swampland Acts of 1849, 1850, and 1860 prompted wetland assessments that provided an economic interpretation. Largescale, but crude surveys of wetlands were done for 15 states, to determine the extent of wetlands before they were drained and converted to agricultural land (Gosselink and Baumann 1980). Later inventories include ones in 1906 by the U.S. Department of Agriculture, 1940 by the USDA Soil Conservation Service, and 1954 by the U.S. Fish and Wildlife Service (Gosselink and Baumann 1980). In the 1960's, as environmental awareness arose, state inventories were initiated. For example, the Texas Department of Water Resources (1980a; 1980b) has completed a series of studies of coastal water resources by river systems and estuaries, including one for the Nueces and Mission-Aransas estuaries, and one for the Guadalupe estuary.

The need to quantify and define the water resource and its value is immediate. In Texas and elsewhere, others have surveyed wetlands and developed economic models to define wetland values based on utilization. For example, Gosselink et al (1974) equated the ratio of the gross national product to the national energy consumption with the ratio of the productivity of a marsh to the energy it consumes. This assesses the economic value of the biological ecosystem that the marsh supports. Other schemes assign general monetary values to various uses of wetlands such that the monetary value of any wetland may be determined. A series of studies in Virginia (Shabman and Batie 1979) assessed market prices of wetland utilization.

Various entities provide information relative to the aquatic resources of Texas. The Texas Water Development Board (1977) assesses and manages both Texas' surface and ground water resources by treating each of the major river basins, and considering their supplies and demands. The Corps of Engineers (1981) provides some estimates on lengths of the major rivers, and capacities of the larger reservoirs. The U.S. Geological Survey also publishes further data concerning river discharges, reservoir capacities, and their water qualities on an annual basis. However, at present, no detailed data assessing all of Texas' water resources, to include the smaller streams and ponds, exists.

Regions of Texas

Texas is a large and diverse state which varies from north to south, and from east to west, as any casual observer could easily tell. Hence, many studies attempt to subdivide the state into a series of homogeneous regions so that observations and theories may be more easily and practically considered on a regional basis.

Most attempts at creating regions within Texas assess primarily the vegetation and ecology, and secondarily the climate, soils, and topography as they effect the biota. For example, Blair (1950) divides the state into the six major biotic regions shown in Figure 1. More recent schemes have described anywhere from 10 to 13 distinct regions. One of the most common and influential classifications today was devised by Gould who in 1969 (revised 1975) divided Texas into 10 regions (Figure 2) by considering climatic, edaphic, topographic, and biotic factors. Maps of soil characters (Goodfrey et al 1973; Arbingast, 1976) in general follow Gould's divisions. The U.S. Forest Service (Bailey 1978) considered biotic, edaphic, topographic and climatic factors which included differentiations between ecoregions of the United States. These ecoregions of the United States resulted in distinguishing 9 regions for Texas (Figure 3).

Most of the schemes to delineate regions of Texas probably indirectly reflect wetland and surface water differentiation and composition; no studies, however, have attempted to correlate these for Texas. Additionally, no arrangements devised include wetland or surface water factors as a criteria for defining the regions.

Wetland Classification

In order to quantify the wetlands and water systems of Texas, one must first classify and be able to identify the various types to be measured. Shaw and Fredine (1956), in U.S. Fish and Wildlife Service

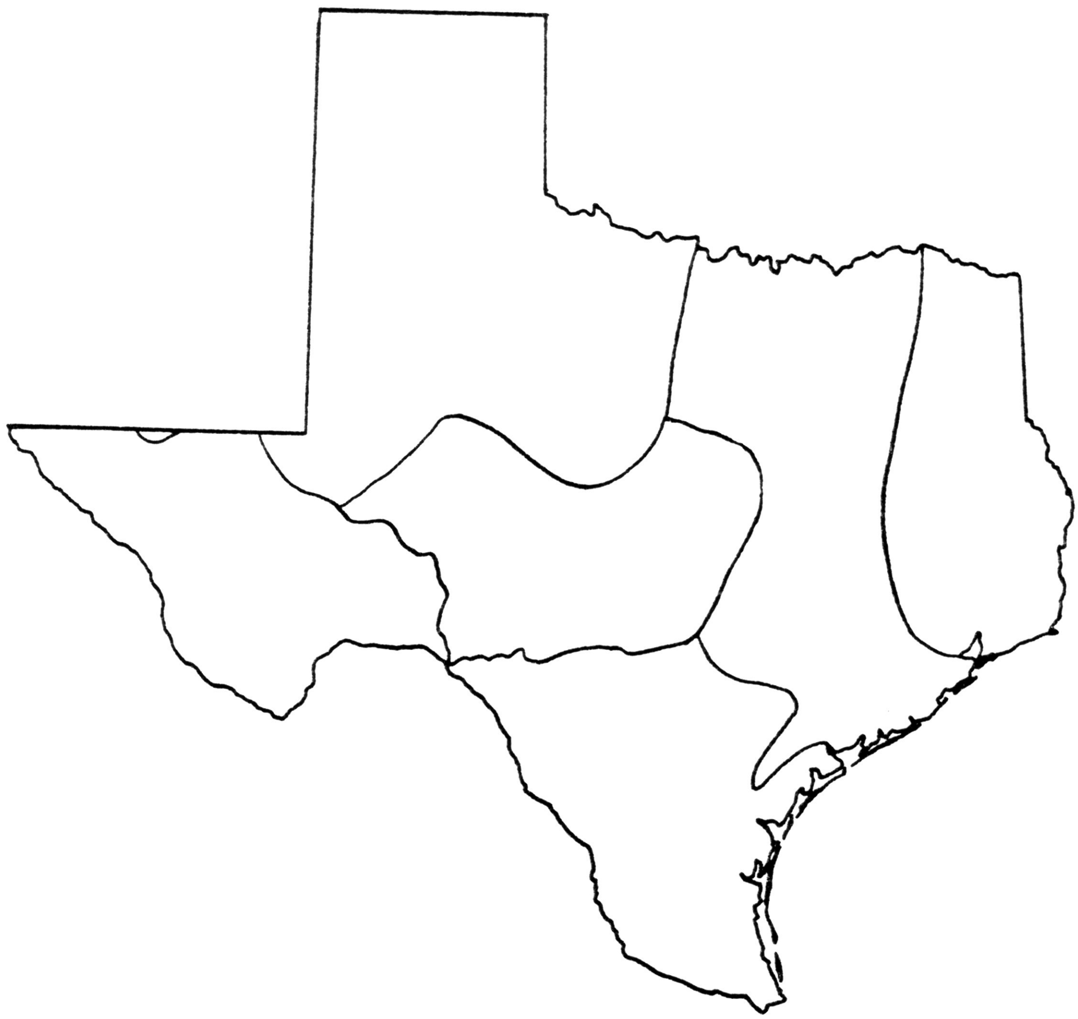

Figure 1. Map of Texas depicting its biotic regions as devised by Blair (1950).

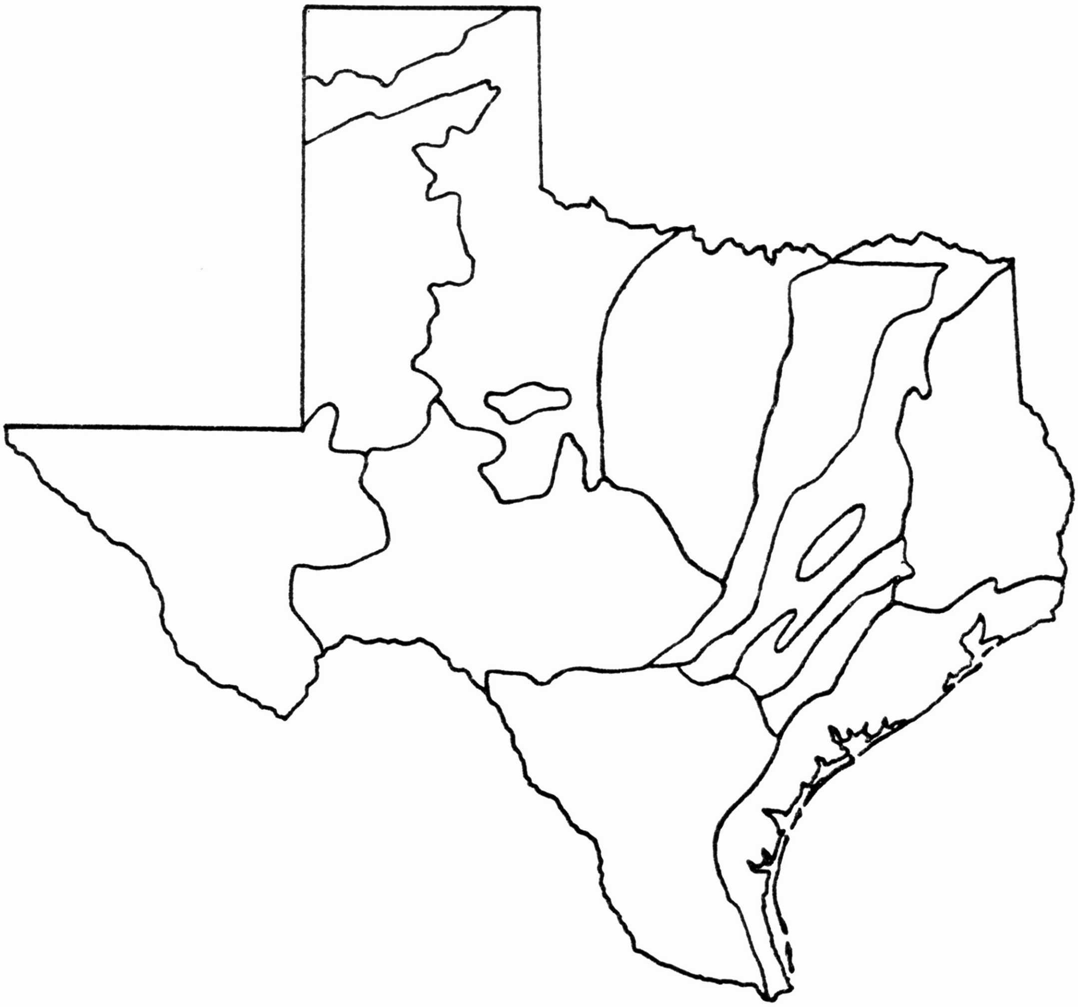

Figure 2. Map of Texas depicting the vegetational regions of Texas as delineated by Gould (1975).

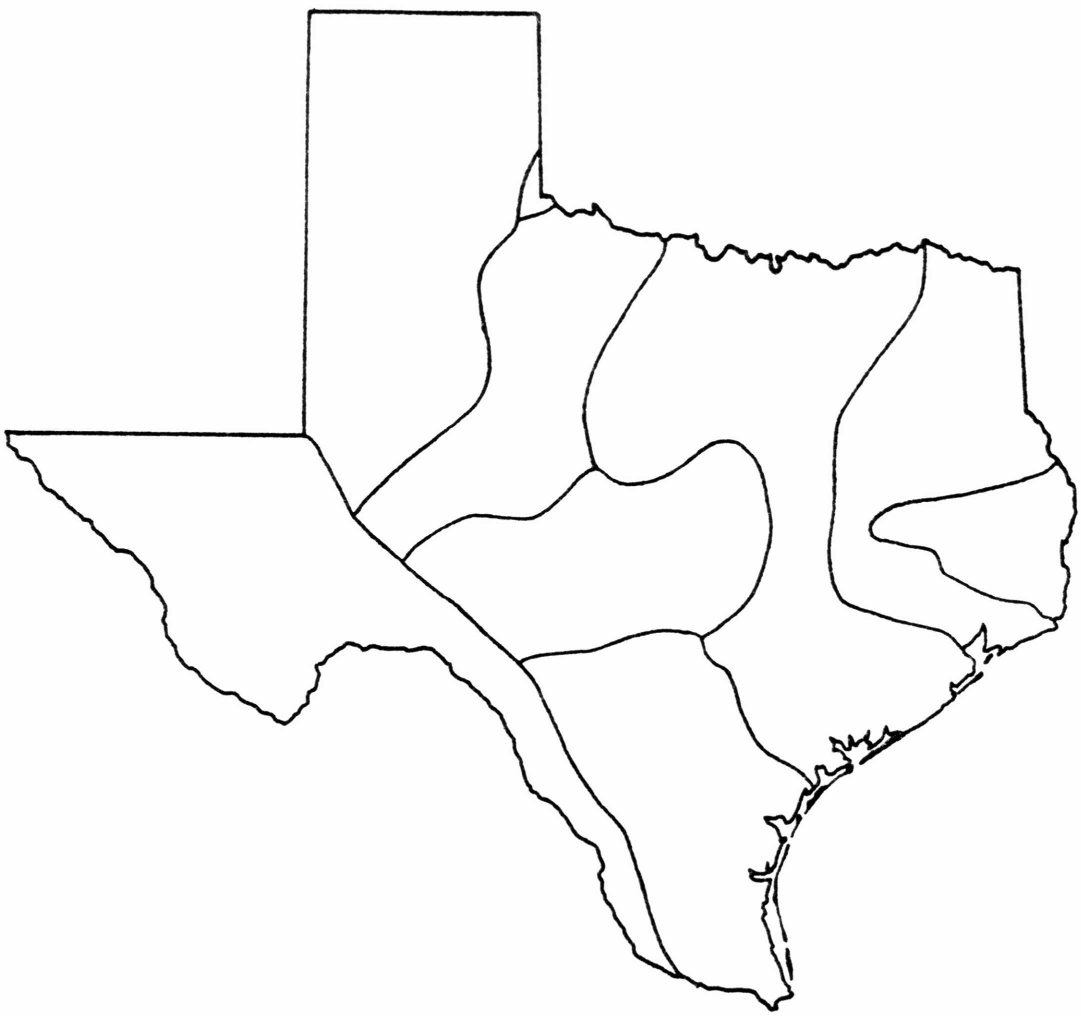

Figure 3. Map of Texas illustrating the vegetational regions of Texas as outlined by the U.S. Forest Service (Bailey 1978).

Circular 39, documented one of the earlier systems of classification. Although this document became quite common and influential, it was criticized for being overly simplistic. Therefore, a new classification procedure was developed by the Fish and Wildlife Service (Cowardin et al 1979).

Cowardin et al's (1979) system classifies wetlands and deepwater habitats by dividing them into 5 major systems: lacustrine, palustrine, riverine, estuarine, and marine. Each wetland system is specifically defined and further subdivided. Their classification scheme also provides units for wetland inventories and mapping and has been adopted by the National Wetlands Inventory.

Ideally, Cowardin et al's (1979) system would be the best for any attempts at quantifying surface water resources. However, when utilizing U.S. Geological Survey maps to delineate wetlands, the USGS system must be employed since the units of Cowardin et al (1979) cannot be derived from the USGS system. The U.S. Geological Survey (1976) identifies six wetland types: intermittent streams, intermittent ponds, perennial streams, perennial ponds, marsh, and wooded marsh. Only three of these wetland types are comparable to Cowardin et al's classes. The U.S.G.S. does not separately identify the estuarine and marine classes.

METHODS

Regions of Texas

Since no other classification scheme specifically considers surface waters when delineating regions, it was necessary to establish geographically continuous, homogeneous wetland regions. Factors concerning water availability and substrate or topographic characters are of primary importance. These are important in determining the potential for the existence of wetlands and additionally influence the type, as well as the quantity, of wetlands that form. All related factors were compiled from existing maps, then these data were synthesized and reexamined for regional similarities and differences.

The most obvious effect on water availability is precipitation. Therefore, maps of annual precipitation within Texas were compiled first. In addition, the mean annual evaporation rate was evaluated since it influences on the amount of water left to support wetlands. The final major factor of water availability was found on maps of mean annual surface runoff.

Concerning substrate and topographic factors, maps depicting relative relief per unit area are important since they indicate the types or patterns of surface runoff expected. Also, soil structure and texture maps are useful in suggesting the relative tendency of infiltration versus runoff.

Other maps of physical, agricultural and biological characteristics were examined secondarily. Maps showing irrigation, acreage, vegetational types, land use, and agricultural crops produced are examples which are used as indicators of wetland amounts and compositions. The use of land-sat photographs of vegetation (Seiscom Delta 1973) were considered. However, these were used only as supplements in support of the other primary factors.

After compiling and analyzing the maps for regional distinctiveness boundaries were drawn. Large aerial photographs of the United States and Texas were used as the base maps for this purpose. The Land-Sat photographic information of vegetation types was used to supplement the aerial photographs. Once the actual boundaries were defined, each region was measured in square kilometers to determine its size.

Wetland Classification

Cowardin et al's (1979) system of wetland classification would be ideal to use in a wetland inventory since it is adapted for wetlands and provides for fine discrimination among wetland types. However, the U.S. Geological Survey (1976) topographic maps only discriminate among perennial streams, intermittent streams, perennial ponds, intermittent ponds, marshes and wooded marshes as the wetland types. The streams are equatable to Cowardin's riverine system, while the ponds are most like his lacustrine system, and the marshes and wooded marshes are of the palustrine system.

Measurement of perennial and intermittent streams treated as linear measurements were in meters, while the other classes were expressed in area units as square meters. Each class was tabulated separately by sample.

Sampling and Measurement

Subsamples were chosen randomly throughout each region after the regions were defined. Care was taken to avoid selecting subsamples near regional boundaries in order to avoid any "edge effect" not indicative of the true regional characteristics. Also, major reservoirs larger than 60 km^2 were avoided for the purposes of this study. Subsamples were taken such that their total equaled 0.5% of each region.

Subsamples consisted of quadrants, 6 km by 6 km (approximately 1/4 of one topographic sheet) of U.S.G.S. 1:24,000 scale topographic maps. For consistency, the lower left quadrant of each topographic sheet, chosen at random, was measured, unless there was a conflict, such as the presence of a major reservoir. If a major reservoir was present in that quadrant, then the upper right quadrant was measured. If that was not possible either, then one of the remaining two, or an adjacent topographic sheet was sampled instead. Wetlands were measured by linear distance (meters) or surface area (square meters) using an electronic digitizer or planimeter. The Electronic Digitizer, Numonics 1224, with a resolution to 0.25 mm, was used. At several times during sampling, 1 km of the map scale was measured to check for accuracy or precision.

Data Analysis

The wetlands were totalled by class for each subsample, and the mean areas and standard deviations per subsample were determined for each region. Values were then calculated per square kilometer. Several statistical multivariate analysis techniques were employed to cluster similar subsamples. The computer program libraries of the Statistical

Analysis System (SAS) (SAS Institute Inc. 1982) and Numerical Taxonomy System (NT-SYS) (Rohlf and Kishpaugh 1972) were used. The NT-SYS procedure used was the UPGMA routine which uses standardized character values to produce both phenetic distance and correlation matrices. The SAS program used was the Canonical Correlation analysis or CANCORR procedure. This procedure asseses the degree of divergence among clusters and samples by employing weighted values which maximize inter-group distinctions. In the process it creates 2 sets of unrelated coefficients which best maximize cluster correlation, and the resulting values may be graphically plotted. Thus, distinct clusters of similar subsamples may be recognized.

Clusters of geographically related subsamples comprised the final regions. Boundaries were redrawn, where necessary, by consulting the maps and aerial photographs as before in light of the sample clusters. New regions were identified or old ones combined where appropriate.

Finally, the mean and standard deviations of each wetland class were recalculated for the new regions. The values were compared and contrasted among regions, and used to describe each.

RESULTS AND DISCUSSION

Regions of Texas

After first examining maps of annual Texas precipitation and evaporation rates (Arbingast 1976), and of annual runoff (Lowry 1958), it became apparent that water availability within the state decreased significantly from east to west, as illustrated in Figures 4 and 5. Annual precipitation ranged from less than 10 inches (25.4 cm) per year in west Texas, up to between 50 or 60 inches (130-150 cm) in far east Texas to greater than 90 inches (229 cm) in the southern portion of east Texas. Annual runoff ranged from none in central and west Texas, to 986,000 m^3 in a small portion of east Texas. Based on these data, one might expect a differentiation of quantities of wetlands throughout the state. For example, there should theoretically be significantly more wetlands along the coast and in east Texas, than in the west or Trans-Pecos region of Texas.

Next, evaluating the relief and elevation differences in the state (Arbingast 1976), one will again observe distinctions from the southeast to the northwest (Figure 6). Differences in relief would be expected to influence the composition by wetland classes in the state. For example, in the southern half of the western Pecos region where there is high relief, there should be proportionately more streams. This is expected since streams tend to concentrate surface water runoff into narrow channels. By contrast, in the high plains of the panhandle the land is nearly flat. There, there is less cause for stream formation, and the wetlands will probably exist mainly as shallow ponds.

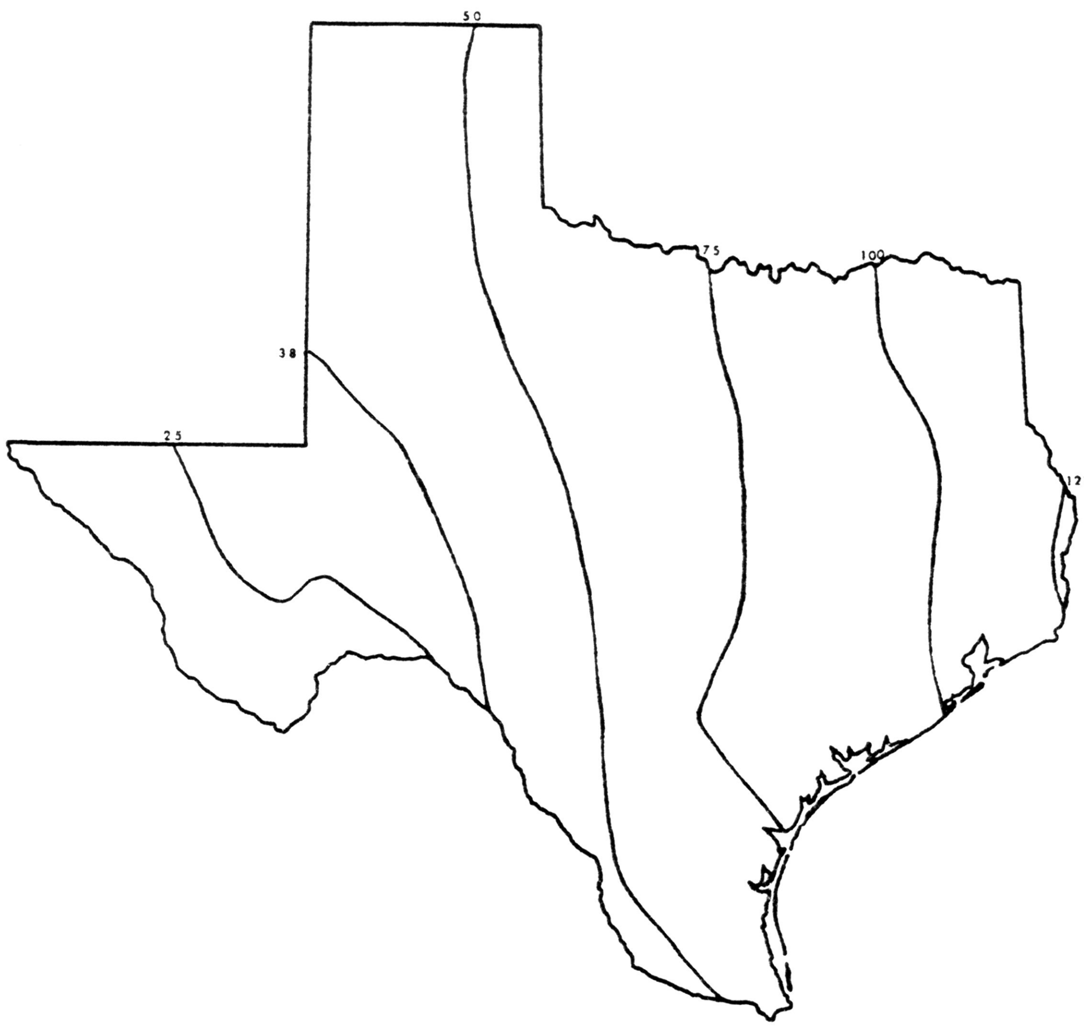

Figure 4. Isohyets of Texas' mean annual precipitation in centimeters [adapted from Arbingast (1976)].

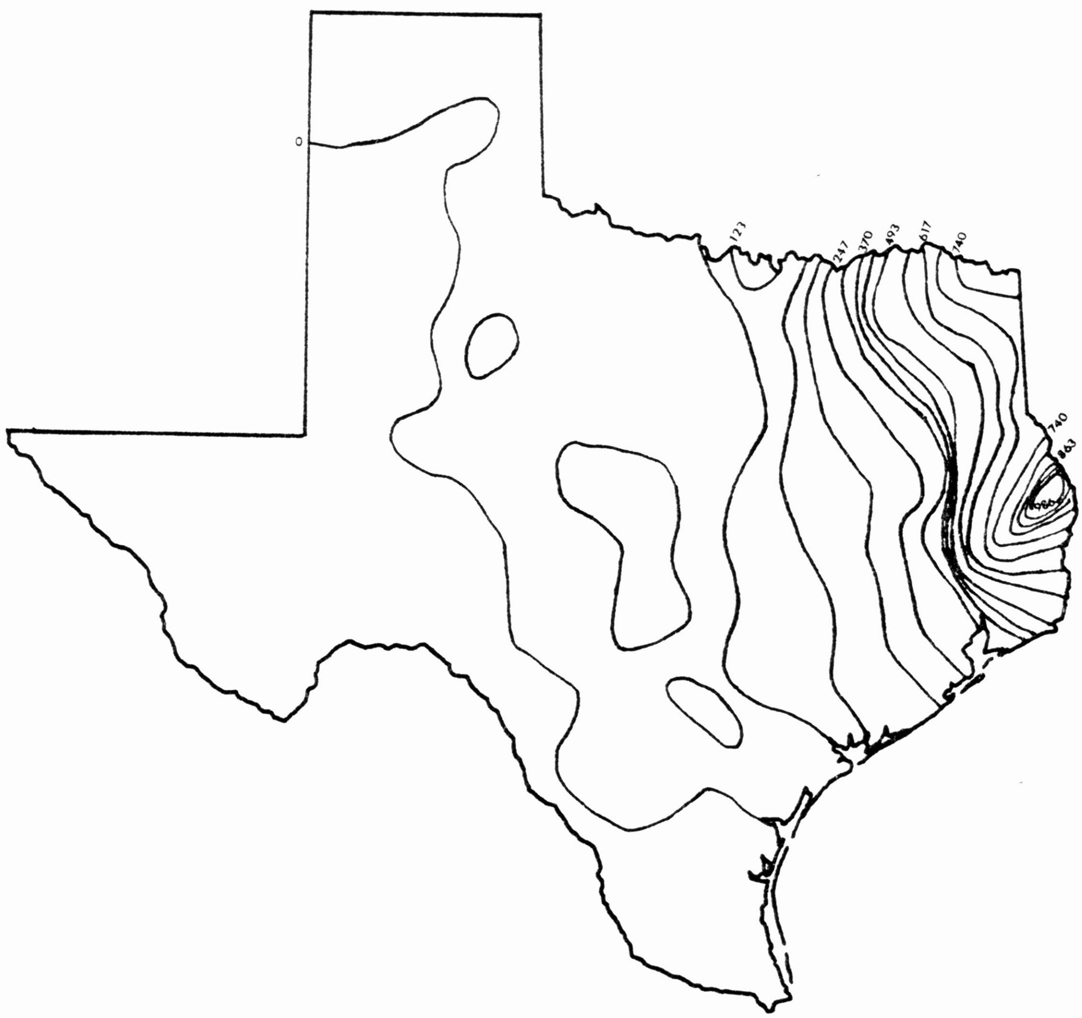

Figure 5. Isograms of mean annual surface water runoff for Texas. Each line is equivalent to approximately 61,000 cubic meters (50 acre-foot) of runoff [adapted from Lowry (1958)].

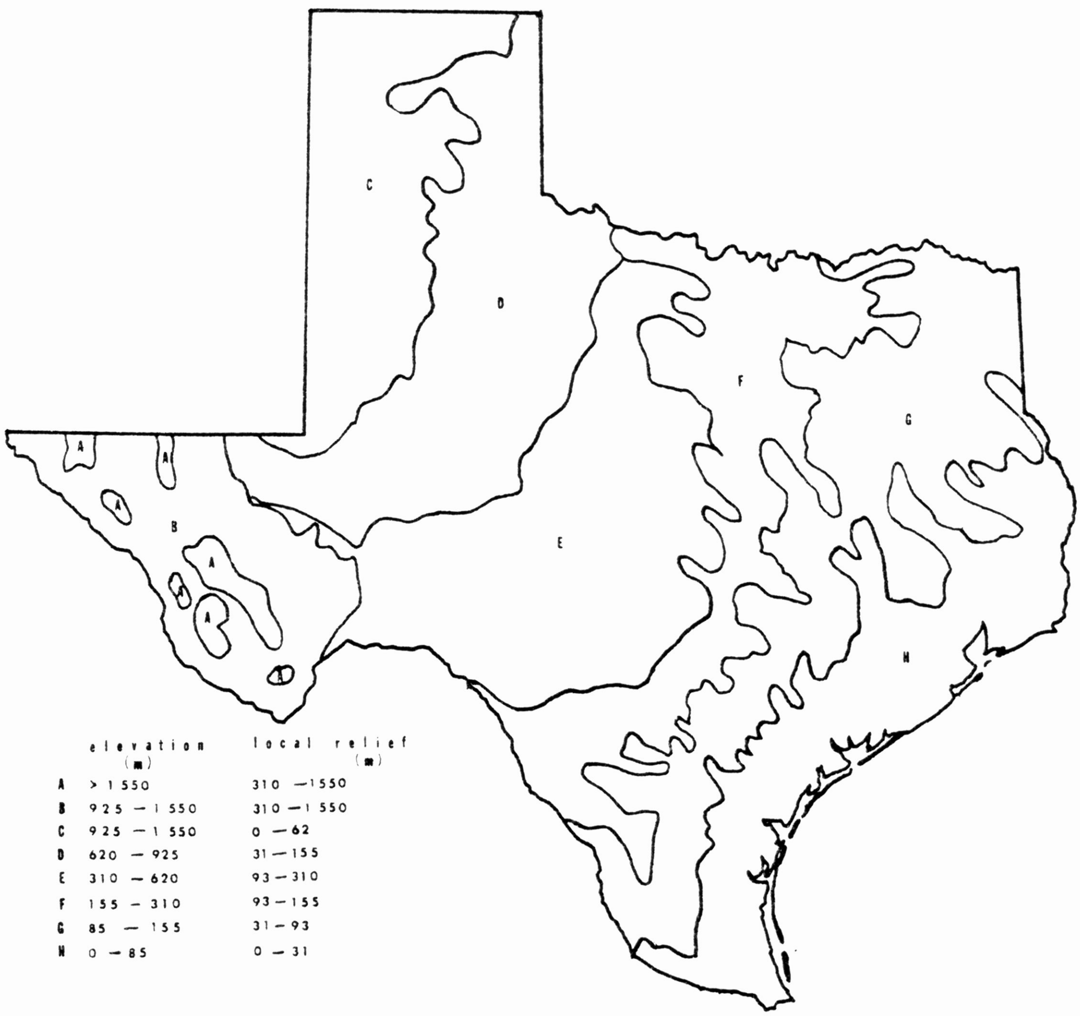

Figure 6. Map of Texas illustrating elevation and local relief throughout the state [adapted from Arbingast (1976)].

Finally, by examining the soils of Texas (Godfrey et al 1973), regional differentiation is apparent, but more complex than merely from east to west (Figure 7). Within Texas, soils vary greatly from the sandy soils in eastern Texas to the poorly drained soils of the coast to the clays in central Texas. Infiltration rates relative to soil types will differ to affect wetland compositions.

As a supplementary source of reference, the vegetational types of Texas (Kuchler 1975) were considered (Figure 8). Vegetation types are dependent upon features such as water availability, soil types, and topography. Therefore, as vegetation differs by type, so might the wetland quantities and compositions.

After considering the data and the patterns that emerged, land-sat maps (Seiscom Delta 1973) and Ryder's Atlas (Ryder Geosystems 1981) of aerial photographs of the United States were used to create the regional boundaries. Thirteen regions resulted (Figure 9). Table 1 lists the characteristics which define each region, and an explanation of each region is presented below.

The North Pecos and South Pecos regions are characterized mainly by their relatively high relief and low annual precipitation. They are distinguishable from one another by topography in that the North Pecos is less uniformly mountainous. The South Pecos region, because of more severe relief is also less suitable for agricultural use. The South Pecos region, because of the mountainous terrain, would probably be characterized by a high proportion of streams per unit area.

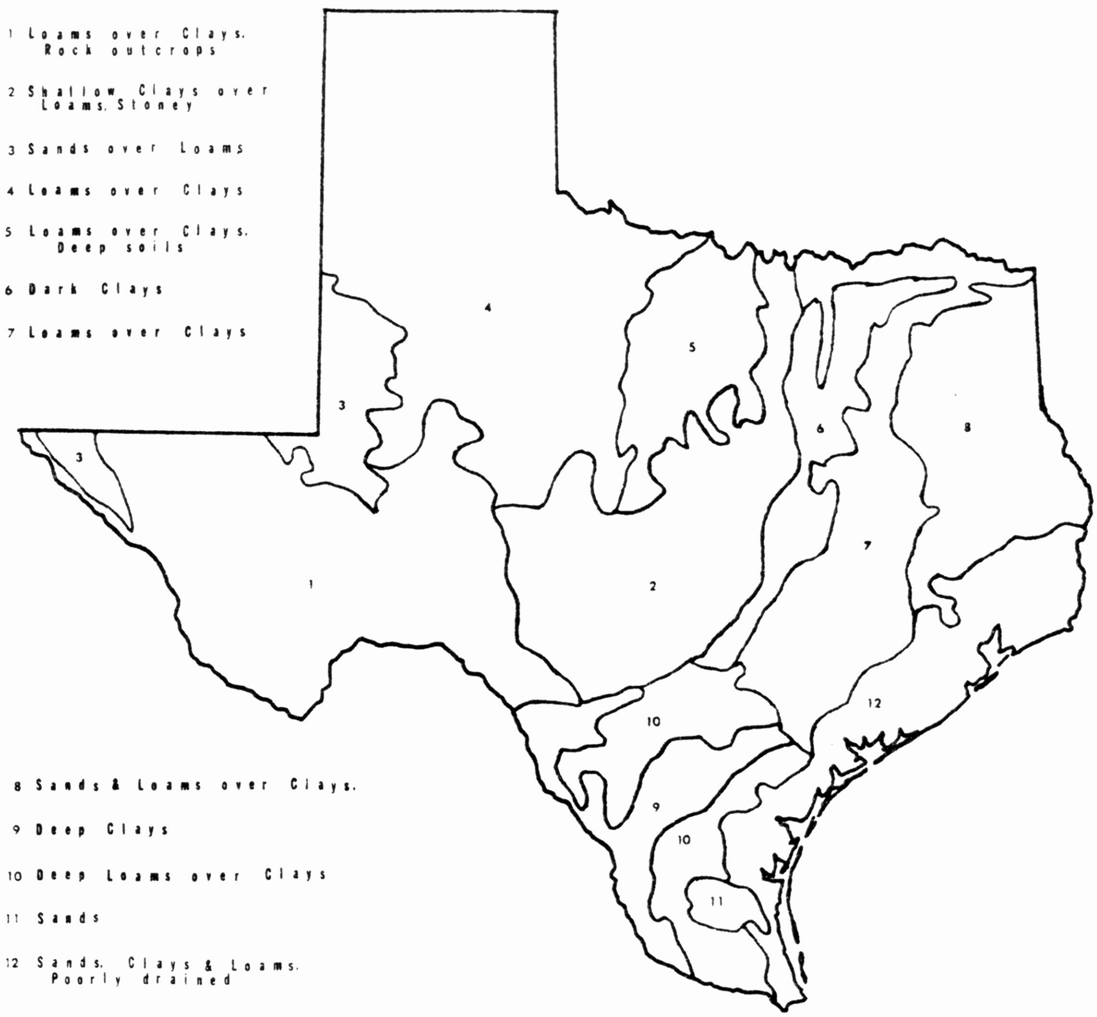

Figure 7. Map illustrating the general distributions of soil types in Texas [adapted from Godfrey et al (1973)].

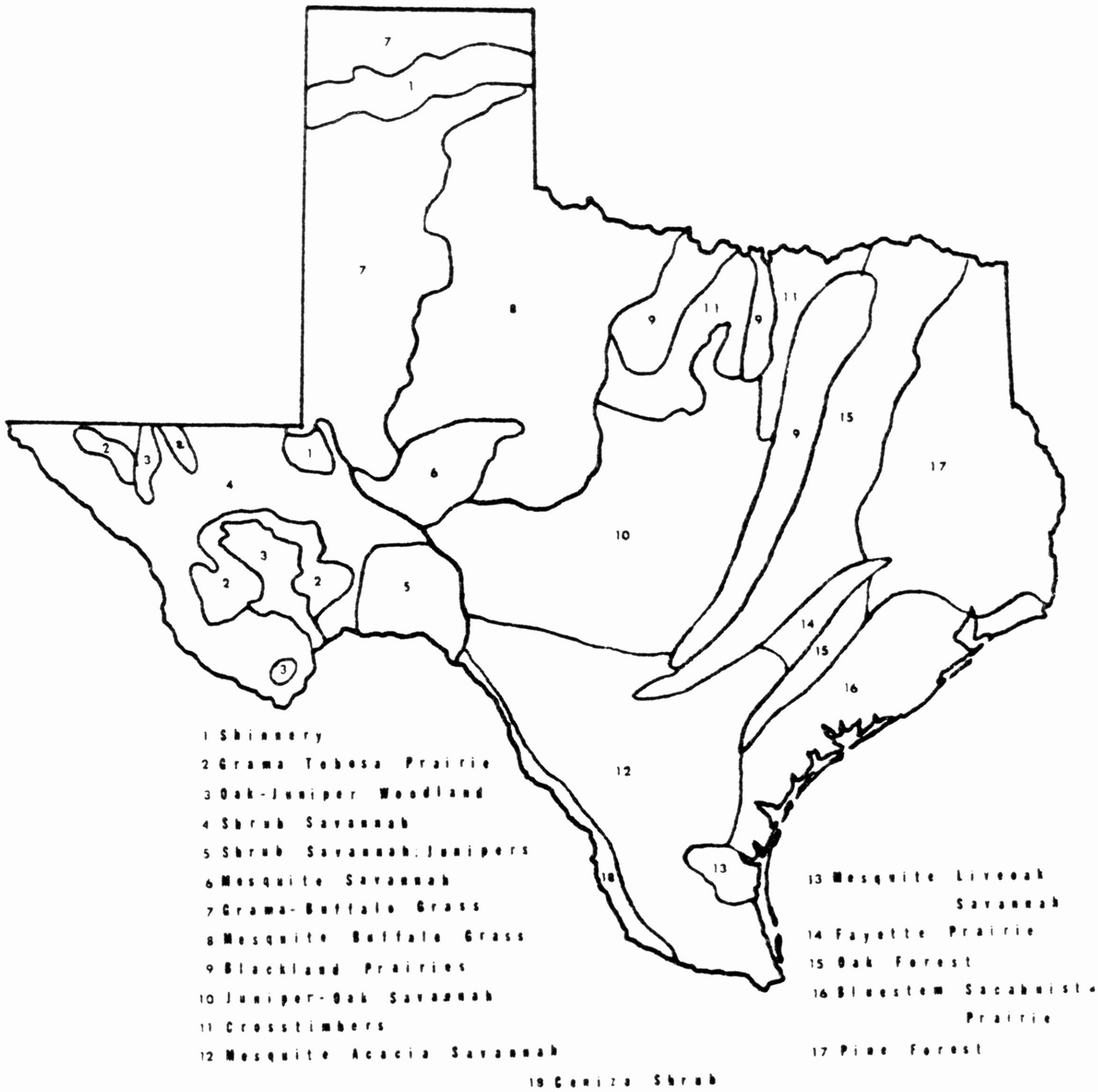

Figure 8. Map illustrating dominant vegetational types characterizing Texas [adapted from Kuchler (1975)].

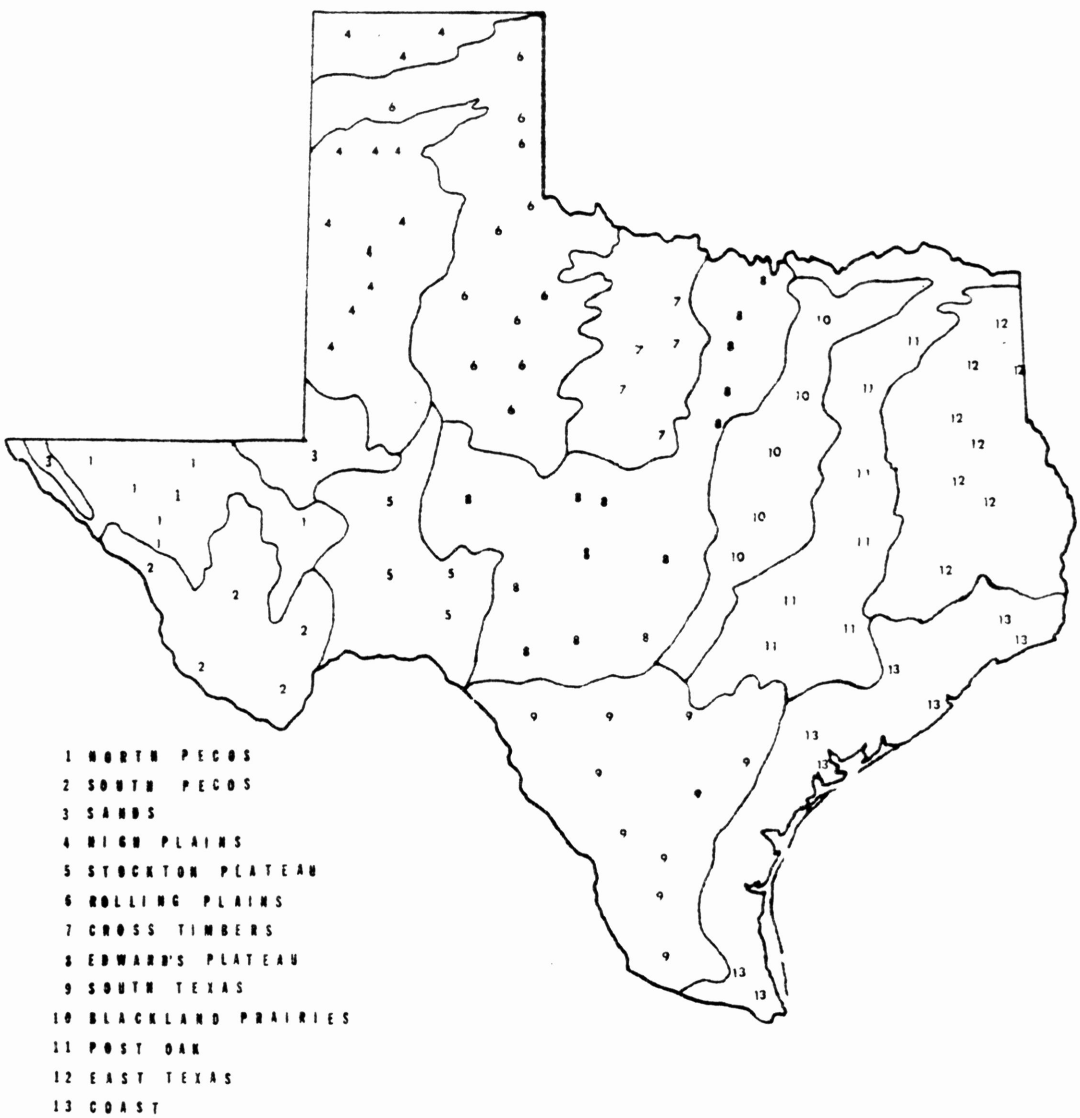

Figure 9. The thirteen preliminary wetland regions of Texas as defined by characteristics of water availability and land form within the state. Subsamples to be measured for wetland quantities are represented by numbers in each region.

Table 1. Comparison of the physical characteristics defining Texas' preliminary 13 wetland regions.

Region	elevation (m)	local relief (m)	mean annual precipitation (cm)	mean annual evaporation (cm)	mean annual runoff (thousand m^3)	soil orders	soil description (surface over subsoil)	vegetation
Edward's Plateau	310-620	90-310 plains w/ open hills	50-75	127-152	62	Mollisols Alfisols	shallow clays over loams; calcareous; stony, cracking	savannah mesquite brush
South Texas	85-310	30-155 irregular to flat plains	50-75	127-152	0-62	Mollisols Alfisols Vertisols	clays & clays loams; neutral to calcareous	mesquite savannah
Blackland Prairie	85-155	30-90 irregular plains	75-100	75-100	62-123	Vertisols	dark clay; calcareous; cracking	blackland prairie
Post Oak Savannah	85-155	30-90 irregular plains	75-100	65-85	123-246	Alfisols Vertisols	loams over cracking clays; slightly acidic	post oak savannah
East Texas	80-155	30-90 irregular plains	100-127	25-65	246-986	Vltisols Alfisols	loams & sands over clays & loams; acidic	mixed forests

Table 1. (cont'd)

Region	elevation (m)	local relief (m)	mean annual precipitation (cm)	mean annual evaporation (cm)	mean annual runoff (thousand m^3)	soil orders	soil description (surface over subsoil)	vegetation
Coast	0-85	0-30 coastal plains	variable	variable	variable	Vertisols	clays, loams, sands; poorly drained to moderately drained; saline	prairie, mesquite brush
North Pecos	>925	155-925 plains w/ low mtns.	<38	190-215	0	Aridisols	loams to clays w/ limestone & igneous rock outcrops	shrub savannah w/ woodlands
South Pecos	>925	620-1550 plains w/ high mtns.	<25	>215	0	Aridisols, Mollisols	loams to clays w/ gypsum & lime; rock outcrops	shrub savannah w/ woodlands
Sands	>925	90-155 plains	<38	190-200	0	Aridisols, Entisols	sands over loams	prairie, shinnery
High Plains	620-925	0-60 flat plains	38-50	152-178	0	Mollisols, Alfisols	loams over clays; lime	prairie, shinnery

Table 1. (cont'd)

Region	elevation (m)	local relief (m)	mean annual precipitation (cm)	mean annual evaporation (cm)	mean annual runoff (thousand m^3)	soil orders	soil description (surface over subsoil)	vegetation
Stockton Plateau	620	90–130 plains & hilly tablelands	25–50	178–203	0	Mollisols	loams; calcareous; rock outcrops	savannah
Rolling Plains	310–925	30–155 rolling plains	15–25	55–75	0–62	Mollisols Alfisols Inceptisots	loams over clays; lime	prairie
Cross Timbers	310–620	90–310 rolling plains	20–30	50–60	0–62	Alfisols	loams over clays; lime	prairie, crosstimbers

The Sands region is characterized by low relief, little rainfall, and sandy soils. It also has limited land use. On the basis of relief alone it is easily distinguished from the Pecos regions. The presence of very few wetlands would be expected in this region of low rainfall and higher infiltration.

The High Plains region differs from the Sands region in that it has loamy or clayey soils. It differs from most other regions because of its very low relief which resembles a flat tableland. Many ponds and few streams per unit area would be expected to form there.

The Rolling Plains are distinguishable from the High Plains based on relief. The Rolling Plains is characterized by moderate relief, with soil and water availability characteristics differing only slightly from the High Plains. Because of its relief, more streams are likely to be present than in the High Plains, but fewer than in the South Pecos area.

The Stockton Plateau, Edward's Plateau, and Cross Timbers regions all are characterized by moderate relief as well. However, each can be differentiated on the basis of water availability and soils. The Stockton Plateau, like the Rolling Plains, receives less precipitation annually, and has less runoff and a greater rate of evaporation than the regions to the east. It also is characterized by is soils with rock outcrops. The Cross Timbers region also differs by its deeper loamy soils. The Edwards Plateau's soils are stony or gravelly cracking clays. Therefore, because these regions differ by soils more than relief, subtle wetland differences are expected.

The remaining 5 regions have lower relief, with all but the South Texas region exhibiting greater water availability. Therefore, a greater quantity of wetlands per unit area is predicted. This should be especially pronounced in the East Texas region, which receives significantly more precipitation than any other region, and in the Coastal region of low relief and poorly drained soils. In these two regions marshes and wooded marshes are most likely to occur.

The Blackland Prairies and Post Oak regions may be distinguished from one another by soil and annual runoff differences, which should be reflected by dominant wetland classes present and by the absolute quantities of wetlands. The surface soils of the Post Oak region are loams while those of the Blackland Prairies are clays. The Post Oak region also has a greater mean annual runoff.

By creating the 13 regions, the wetlands may be sampled and measured systematically. Results of sampling can then be used as a test of the forementioned arrangements.

Sampling and Data Analysis

Ninety-seven subsamples were chosen (Figure 9) and represent 0.50% of the area of Texas. Subsamples were measured and totalled by wetland class and the means and standard deviations calculated for each region (Table 2). However, standard deviations in most cases were larger than the means themselves, and therefore (1) some subsamples may have been placed in the wrong region, indicating that the regions themselves need to be reexamined and redrawn, or(2) more samples need be taken to reduce

Table 2. Means and standard deviations by wetland class for each of the 13 preliminary wetland regions of Texas. The upper value is the regional mean and the lower being the standard deviation.

Region	Perennial Ponds (m^2)	Intermittent Ponds (m^2)	Perennial Streams (m)	Intermittent Streams (m)	Marsh (m^2)	Wooded Marsh (m^2)
East	282,239	9,435	16,433	40,973	121,234	448,704
Texas	361,535	12,181	15,239	10,751	231,264	793,609
South	1,285	5,812	439	69,547		
Pecos	1,503	5,840	982	20,280		
North	1,498	11,071		27,865		
Pecos	1,911	9,798		26,249		
High	1,604	412,132		2,896		
Plains	2,248	572,378		2,712		
Rolling	29,429	21,579	1,363	53,811		
Plains	18,833	12,631	2,823	16,189		
Cross	181,601	14,897	2,261	70,286		
Timbers	58,492	14,856	3,261	16,366		
Blackland	103,987	23,189	4,134	39,424		
Prairies	20,962	22,132	5,782	5,563		
Edward's	53,861	14,717	1,912	48,989		
Plateau	56,096	16,740	3,362	10,121		
Sands	1,347					
	1,905					

Table 2. (cont'd)

Region	Perennial Ponds (m^2)	Intermittent Ponds (m^2)	Perennial Streams (m)	Intermittent Streams (m)	Marsh (m^2)	Wooded Marsh (m^2)
Stockton	362	3,753		44,069		
Plateau	289	4,775		10,749		
South	42,233	20,757		29,122		
Texas	40,767	12,440		12,854		
Post	195,723	10,193	4,107	50,343	2,341	6,206
Oak	110,923	11,656	8,221	15,722	4,014	16,419
Coast	69,420	48,351	21,733	29,156	1,413,902	
	73,199	113,387	20,824	21,413	2,661,550	

the variance. The latter was checked for the High Plains Region (Table 3), but the standard deviations did not decrease significantly.

The multivariate analysis techniques were used to provide an independent test of the homegenity within regions and the distinctiveness between them. The analysis did in fact indicate a need for boundary adjustments. An examination of the phenograms (figure 10) reveals that the East Texas region is distinct. However, one Post Oak subsample appeared more similar to East Texas than the Post Oak region and so was reallocated as such.

Next, the North Pecos region was corrected by incorporating the Sands region, and the two adjacent High Plains subsamples. In addition one southern North Pecos subsample was placed within the South Pecos region.

The Stockton Plateau and western Edward's Plateau region were then combined as a Plateau region. The northern Edward's Plateau subsamples correlated well with the Cross Timbers area and were thus reallocated to that region.

Finally, the South Texas region required major boundary revision. Western South Texas subsamples and one Coastal subsample, all of which occurred along the lower Rio Grande Valley, correlated at a high level while the other South Texas subsamples appeared unrelated to them, correlating as a separate group. Therefore a new Rio Grande region was created.

These revisions were tested using the CANCORR Procedure (SAS Institute Inc. 1982). The newly correlated groups of subsamples were

Table 3. Comparison of the standard deviations calculated for the High Plains wetland region as sample numbers increase. With 8 samples measured, 0.5% of the region is sampled. Values are in meters and square meters per sample. Values in parentheses equal the mean wetland quantity for the corresponding number of samples measured.

Sample Size	Perennial Ponds	Intermittent Ponds	Intermittent Ponds
2	2,887.372	377,934.01	5,108.818
3	2,357.529	292,383.68	4,515.604
4	2,041.680	241,736.46	3,688.440
5	1,826.134	671,045.45	3,207.900
6	2,003.894	608,097.24	2,880.269
7	2,325.873	591,949.39	2,895.685
8[2]	2,248.802 (1,604.353)	572,378.24 (412,132.732)	2,711.876 (2,895.677)
9	2,130.623	539,318.113	2,573.578
10	2,063.817	509,564.336	2,609.920
11	2,037.218	483,599.441	2,609.822
12	2,118.505 (1,941.309)	476,960.702 (419,239.456)	2,589.907 (2,280.231)

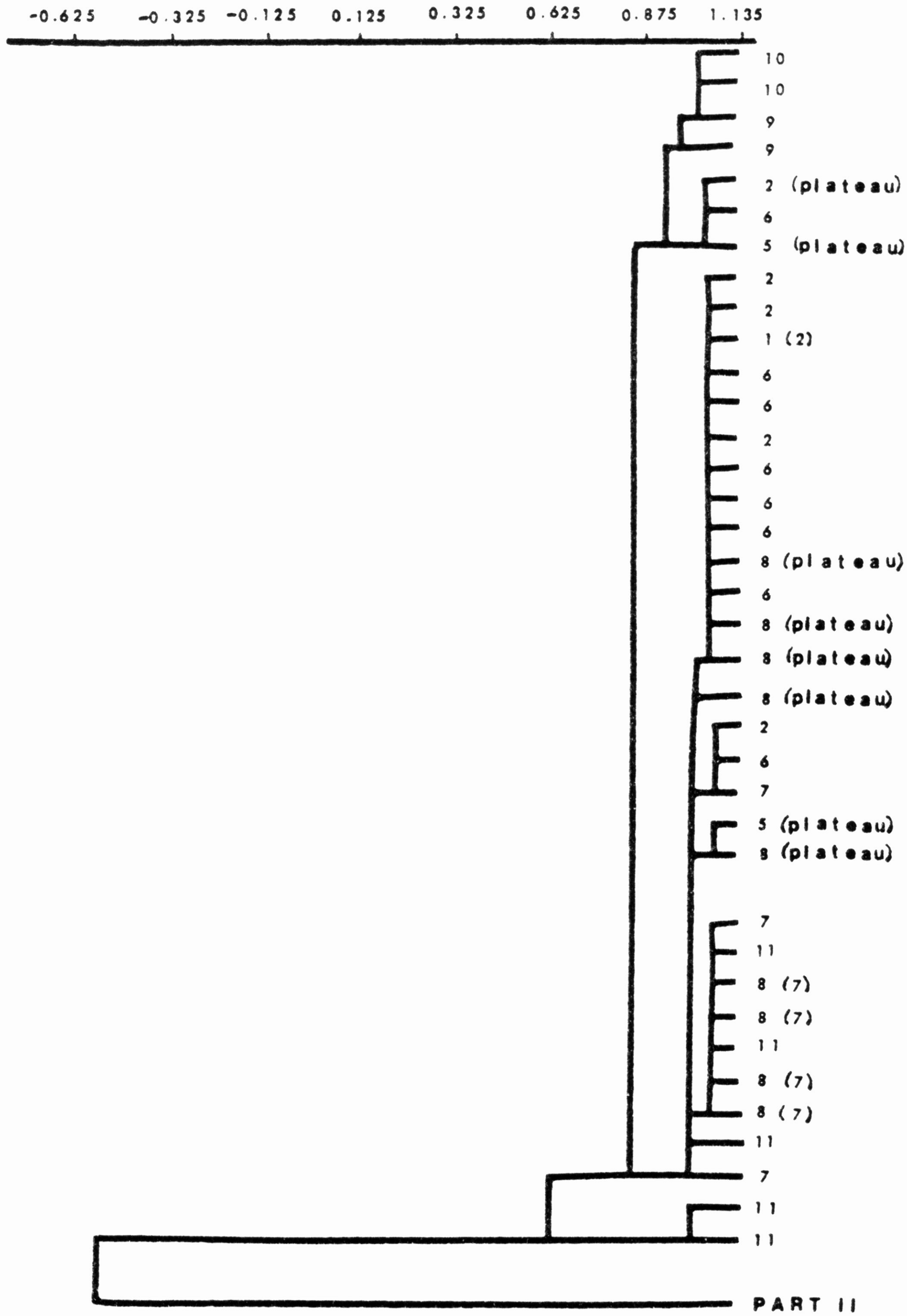

Figure 10. Correlation phenogram of wetland samples indicating initial and revised allocations. Subsample region is represented numerically as defined in the legend of Figure 9. Numbers in parentheses represent revised regional classification of subsamples as necessary.

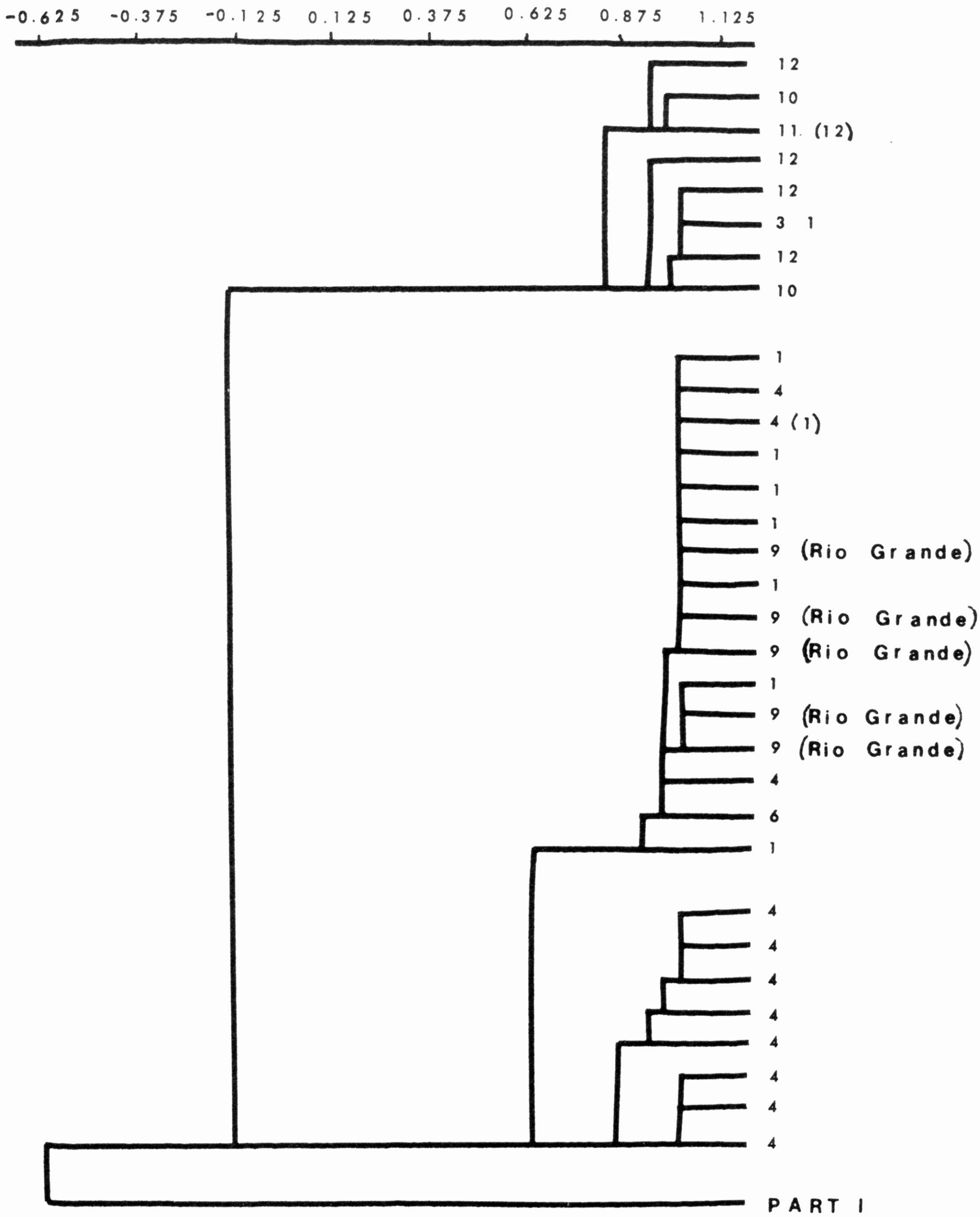

Figure 10. (cont'd)

relabelled and clustered using the CANCORR program (Figure 11). The regions generally appeared distinct. Where regions like the Rio Grande and North Pecos regions clustered together, they were kept as distinct regions since they are geographically non-continuous.

Boundaries were redrawn (Figure 12) by examining the maps and aerial photographs used earlier while considering the results of the statistical tests. Additional sampling was then done and statistically analyzed in problematical areas. The sizes of the regions were remeasured and the means, standard deviations calculated for each (Tables 4&5).

Perennial ponds and intermittent streams consistently had the lowest standard deviations relative to the means, while the other classes were less predictable within regions. Regional distinctions are therefore best reflected by the quantities of intermittent streams (Figure 13) and perennial ponds (Figure 14). Intermittent streams especially become a major factor in differentiating between geographically adjacent regions. The difference between the means of the North Pecos and South Pecos regions is particularly striking with the South Pecos having almost 8 times more meters of intermittent streams. Furthermore, the South Pecos region cannot be confused with the neighboring plateau region which has also less intermittent streams.

The Post Oak region is another area with quantities of intermittent streams being significantly different from the adjacent Blackland Prairie and East Texas regions. The Post Oak region has more meters of

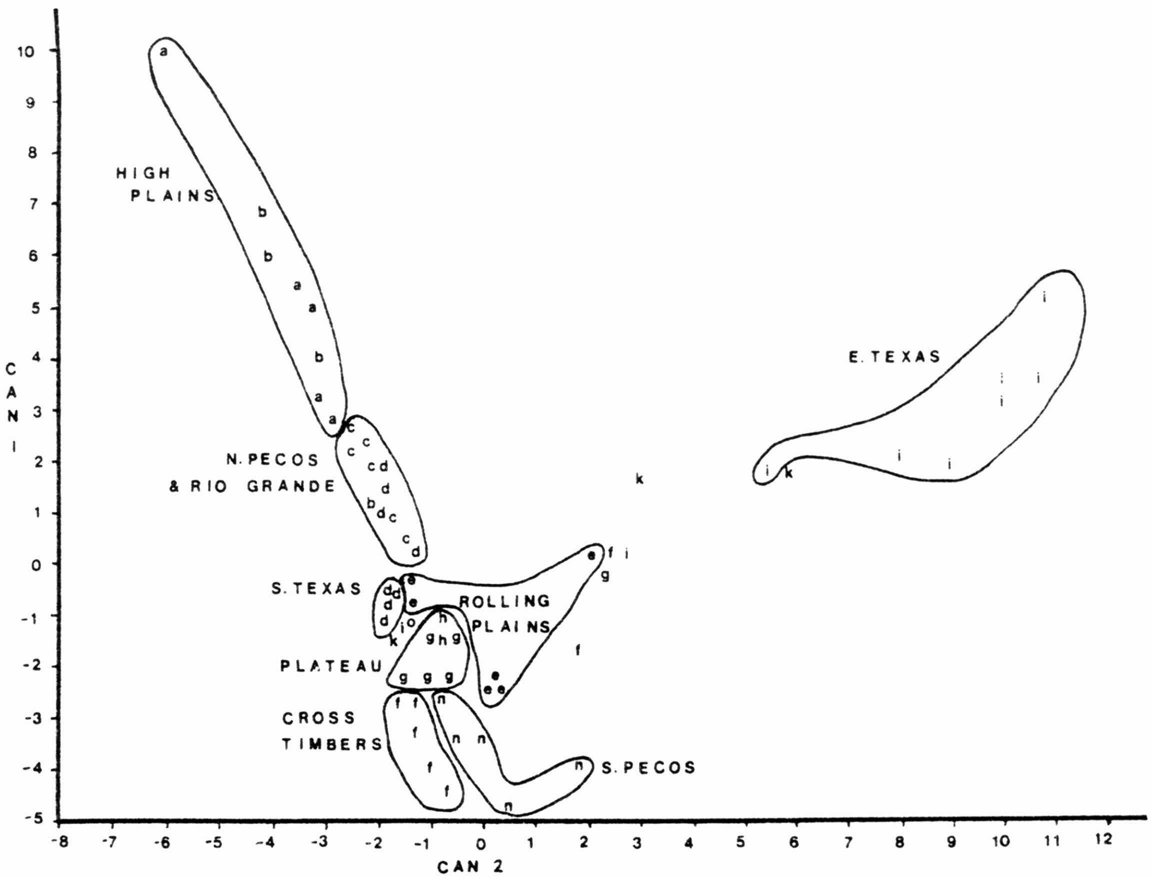

Figure 11. Canonical correlation clustering of related subsamples to revise the 13 preliminary wetland regions. Related subsamples are circled and labelled as to the appropriate region.

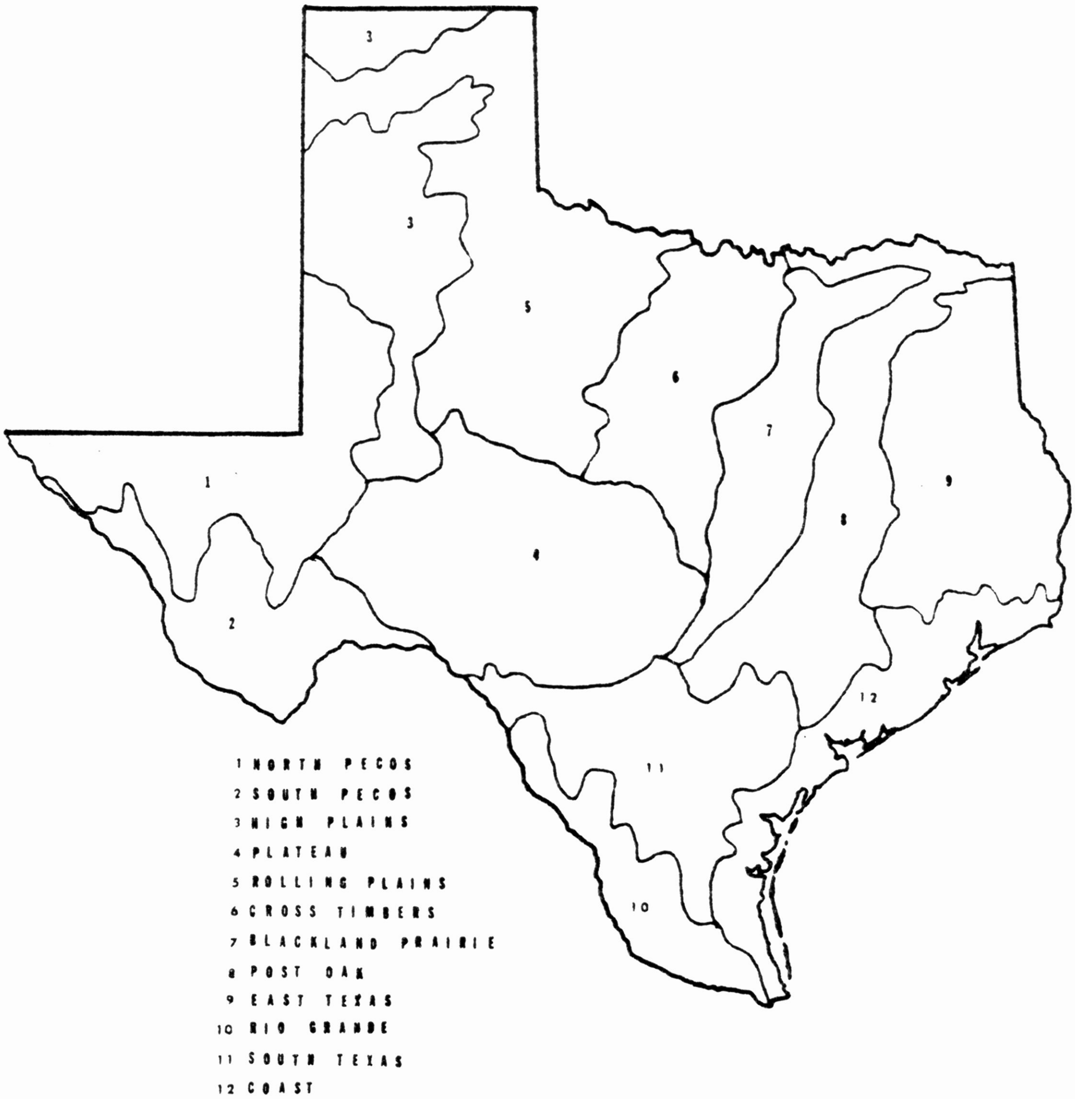

Figure 12. Revision of the wetland regions of Texas based on the results of the statistical correlation phenogram and canonical coefficient clustering.

Table 4. Comparison of the average wetland quantities per square kilometer in each of the 12 revised wetland regions. Values are given in meters and square meters, with the numbers in parentheses equalling the standard deviations.

Region	Per. Pond (m^2)	Int. Pond (m^2)	Per. Stream (m)	Int. Stream (m)	Marsh (m^2)	Wood Marsh (m^2)
North Pecos	37.26 (49.88)	626.34 (917.80)	0	254.01 (328.07)		
South Pecos	46.88 (46.27)	140.99 (153.51)	10.17 (24.55)	1,965.60 (533.51)		
High Plains	53.37 (59.29)	13,844.38 (13,499.62)	0	42.08 (49.85)		
Plateau	315.15 (821.31)	422.55 (497.52)	37.85 (91.10)	1,290.04 (292.80)		
Rolling Plains	817.49 (523.15)	599.44 (350.87)	37.86 (78.43)	1,494.76 (449.764)		
Cross Timbers	3,766.04 (1641.62)	272.52 (304.60)	54.06 (78.61)	1,627.73 (431.29)		
Blk. Prairies	2,888.56 (582.27)	644.14 (614.78)	114.83 (160.61)	1,095.13 (154.896)		
Post Oak	5,698.10 (3,289.22)	308.08 (347.25)	32.16 (78.77)	1,550.35 (187.16)	75.87	201.12
East Texas	7,398.73 (9,486.82)	247.82 (319.41)	473.06 (399.10)	1,065.80 (353.76)	2,993.43	11,079.12

Table 4. (cont'd)

Region	Per. Pond (m^2)	Int. Pond (m^2)	Per. Stream (m)	Int. Stream (m)	Marsh (m^2)	Wood Marsh (m^2)
South Texas	1,803.78 (1041.03)	517.84 (380.32)	0	1,061.43 (162.97)		
Rio Grande	227.23 (229.38)	664.77 (316.08)	0	430.31 (139.81)		
Coast	33,666.0	825.32	431.41	710.51 (501.86)	4,666.61	

Table 5. The 12 wetland regions of Texas indicating the area within, and number of samples from, each region.

Final Region	Region Size (km^2)	% State	Number of Subsamples	% area sampled
North Pecos	65,507.817	8.9	9	0.49
South Pecos	40,440.042	5.5	6	0.60
High Plains	61,931.088	8.5	10	0.58
Plateau	90,651.369	12.4	12	0.50
Rolling Plains	10,5523.070	14.4	12	0.41
Cross Timbers	54,750.057	7.5	10	0.66
Blackland Prairies	41,120.664	5.6	5	0.44
Post Oak	62,007.779	8.5	6	0.35
East Texas	62,172.142	8.5	9	0.52
South Texas	61,091.257	8.3	6	0.35
Rio Grande	23,485.341	3.2	5	0.77
Coast	63,920.660	8.7	6	0.34

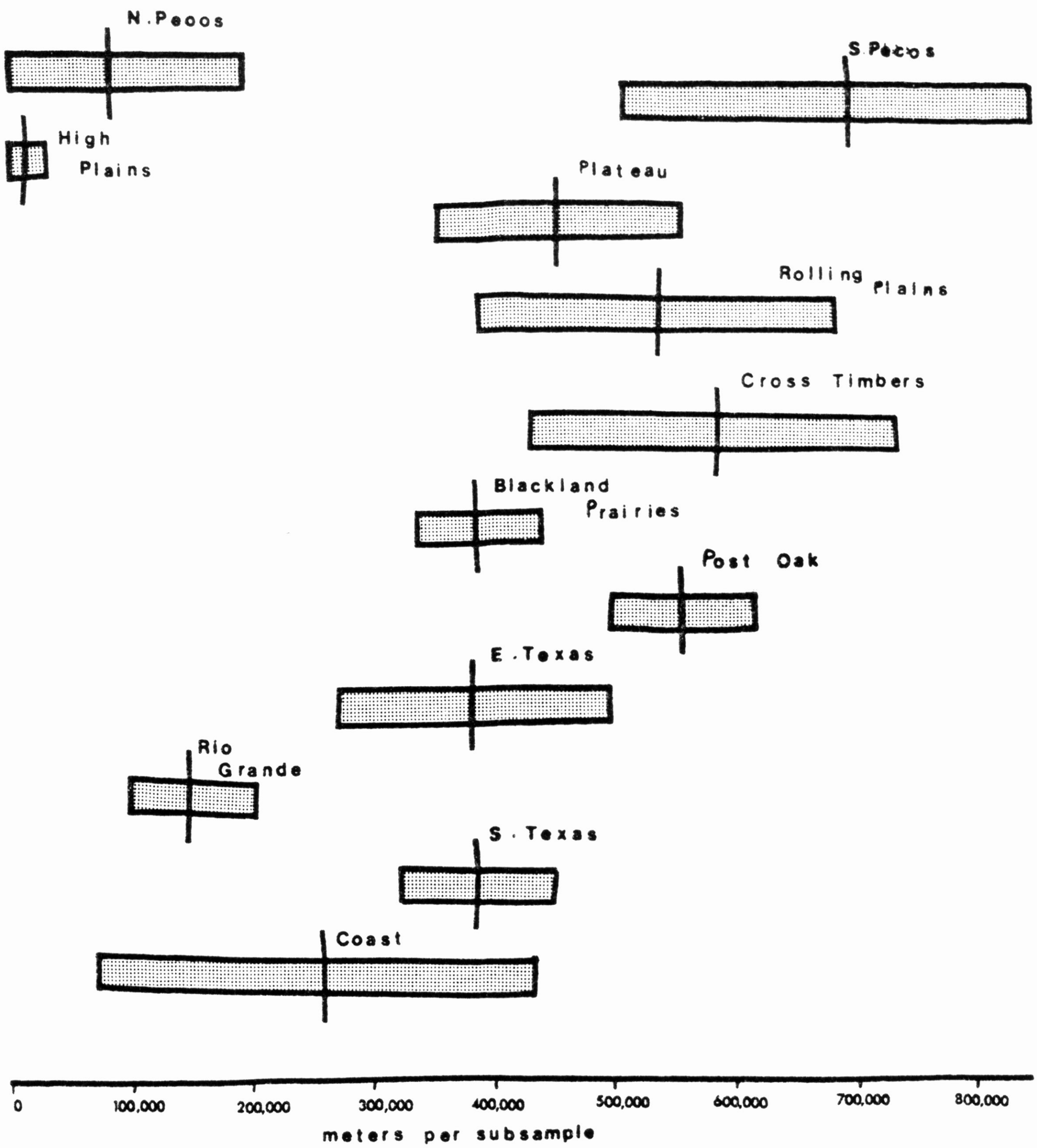

Figure 13. Graphic comparison of quantities of intermittent streams within the 12 wetland regions. As plotted, each vertical line equals the region's mean, with one standard deviation (stippled) shown around the mean.

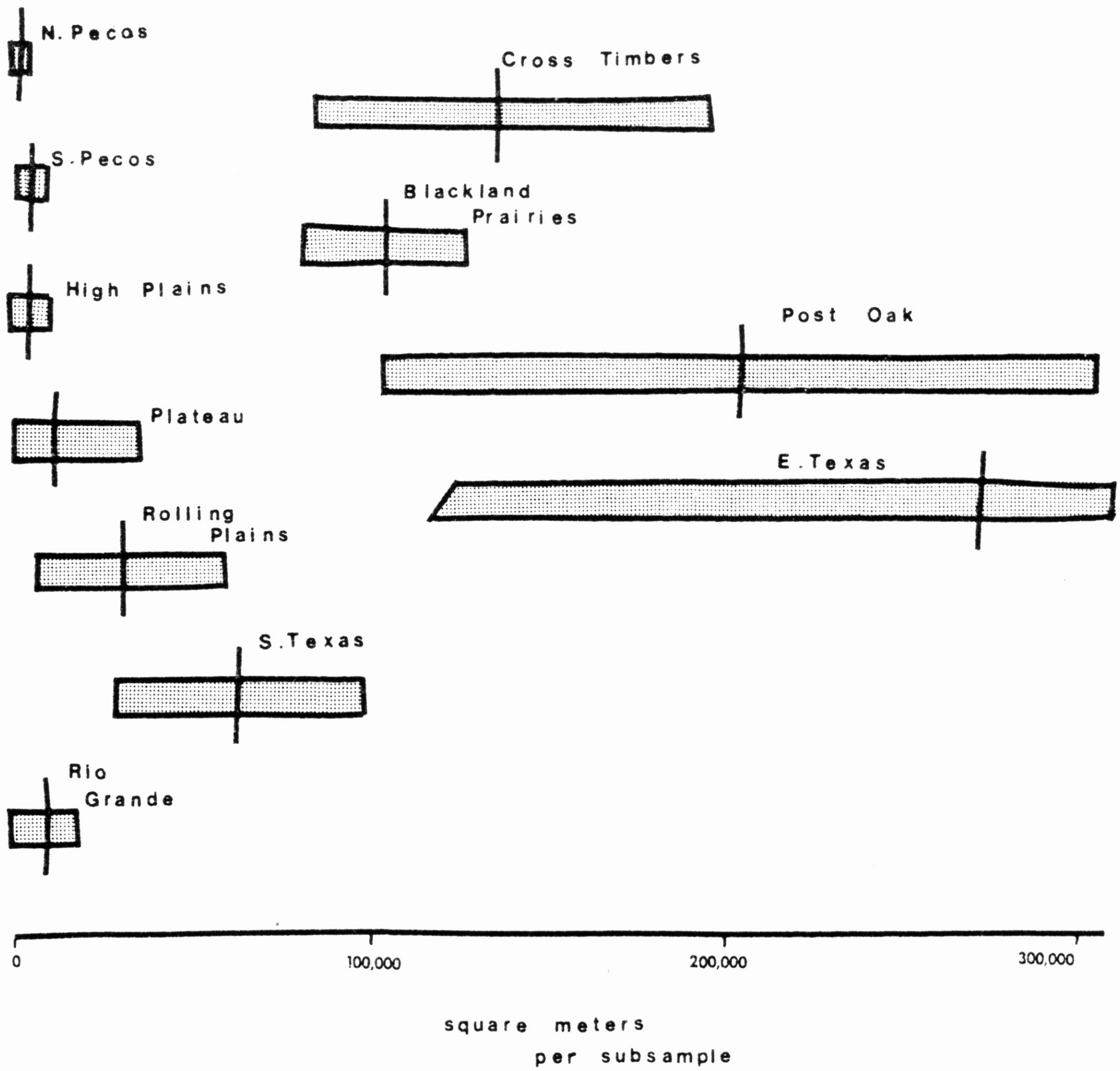

Figure 14. Graphic comparison of quantities of perennial ponds within the 12 wetland regions. As plotted, each vertical line equals the regional mean, with one standard deviation (stippled) shown around the mean.

intermittent streams per unit area than the other two, and there is no overlap in standard deviation.

The creation of the Rio Grande region also appears justified. The South Texas region has over twice the quantity of intermittent streams per unit area that the Rio Grande has.

Regarding perennial ponds, it appears that their quantities increase in the eastern regions of the state. The Cross Timbers, Blackland Prairie, Post Oak, and East Texas region are all thus different from the western regions. Consequently, the Cross Timbers region segregates from the Rolling Plains and Plateau regions although this was not evident by merely comparing only intermittent streams. In addition, the decrease from east to west is also apparent when comparing the quantities of perennial ponds of South Texas to the more westerly Rio Grande region.

The High Plains region cannot be differentiated based on either of these two factors. However, the region has almost twice the quantity of intermittent ponds that any other region has, and almost ten times that of some regions. Other than in this instance, however, intermittent pond quantities do not greatly vary between regions and cannot be used as a major factor when distinguishing them.

Perennial streams is another wetland class which cannot be reliably used to typify any region. Their occurrence within any region is variable and unpredictable.

The marsh and wooded marsh classes are also in sporadic distribution. In general if marshes are present in an area, then it should be part of East Texas, the Post Oak region or the Coast. If wooded marsh is present, than the area belongs to either the Post Oak or East Texas region. Also, if they occur in quantities exceeding an average of 750 m^2/km^2, then the area is likely to be in the East Texas or Coastal regions. The absence of marshes and wooded marsh can not be used as their occurrence within the 3 regions is variable.

The Coastal Region was not included in the clustering procedures shown in Figures 10 & 11, nor tested for its standard deviation as it is expected to be a variable region which gradually changes as it progresses inland. Therefore, its mean values were obtained by measuring subsamples along a transect extending from the Gulf of Mexico to the margins of the other inland regions. Still, the Coastal region, being highly complex, is more adequately treated using field analysis, or by using delineations of aerial photographs as outlined by Kelsch and Hendricks (1982). Additional treatment will be made possible by the U.S. National Wetlands Inventory which was recently completed for the U.S. Fish and Wildlife Service. This inventory used Cowardin's 1979 wetland classification system.

Total values for each region were calculated by extrapolating the mean values for whole regions and the regional values were summed to get the state total (Table 6). Based on this study, Texas has 22,896 km^2 of perennial ponds, 1,182 km^2 of intermittent ponds, 74,500 km of perennial streams, 790,319 km of intermittent streams, 489 km^2 of marsh, and 700 km^2 of wooded marsh. East Texas emerges as the region most rich in

Table 6. Comparison of wetland class totals for each wetland region and the total for the state of Texas.

Region	Perennial Pond (km^2)	Intermittent Pond (km^2)	Perennial Stream (km)	Intermittent Stream (km)	Marsh (km^2)	Wood Marsh (km^2)
North Pecos	2.44	41.03	0.0	16,639.4	0.0	0.0
South Pecos	1.90	5.70	411.15	74,488.99		
High Plains	3.31	857.40	0.0	2,606.28		
Plateau	28.57	38.31	3,430.89	116,940.0		
Rolling Plains	86.26	63.26	3,995.61	157,730.0		
Cross Timbers	206.19	14.92	2,959.99	89,118.33		
Bkl. Prairies	118.78	26.49	4,721.78	43,032.26		
Post Oak	353.33	19.10	1,993.96	96,133.83	4.71	12.47
East Texas	459.99	15.41	29,410.88	66,263.24	186.11	688.10
South Texas	110.19	31.64	0.0	64,843.89		
Rio Grande	5.34	15.61	0.0	10,106.03		
Coast	21,520.0	52.76	27,575.89	45,416.52	298.29	
TOTAL	22,896.29	1,181.61	74,500.13	790,318.75	489.105	700.57

all but the intermittent pond and stream classes of wetlands, if the coastal region is excluded. The coastal area itself is rich in all classes except wooded marshes. However, being adjacent to the Gulf of Mexico, much of its wetland resource would have higher salinity contents than the normal inland freshwater wetlands and could be considered separately. The western drier regions, while poorer in perennial wetland classes, are relatively rich in the intermittent ones.

Error

There is certainly some concern that true estimates of wetland areas may be quite different from those predicted. The large variances of most parameter means reflect the difficulty in arriving at reliable estimates since wetland distributions are non-uniform. Other factors such as planimeter error and human error in measurement are relatively insignificant. Factors adding an additional error component result from the use of USGS maps. These maps have incorporated a level of human error in their compilation and are typically the result of less than recent photographic interpretations. Furthermore, in photo-revised maps, it was often unclear as to which ponds were perennial and which were intermittent. Where indeterminable, they were assumed to be perennial.

Finally, though subsamples were chosen randomly, bias against the major rivers of Texas is likely. When Texas' 14 major rivers and a few major tributaries were measured, an additional 7,291.2 km resulted, which is 9% more than was estimated in table 6.

CONCLUSIONS

The results support the theories regarding regional differentiation of relative wetland composition and quantities based on topography, substrate characteristics and water availability. Western regions are less water abundant. Wetland composition there is reflective of topography with mountains of the South Pecos concentrating the available runoff as streams, and flat plains of the High Plains allowing for more ponds. Sandy soils allow for more infiltration and less surface water. Eastern and Coastal regions are Texas' water rich areas. They have good amounts of all types of wetlands, including perennial streams, marsh, and wooded marsh.

The estimates obtained include sampling error, measurement errors, and experimental technique error. Accuracy and precision of the results should be considered with the resulting margin of error.

This study may serve as a framework for future wetland analysis in Texas. Regional uses by wetland classes can be identified to describe economic values of wetlands and wetland demand for management and planning purposes. The Coastal region, being highly complex cannot be adequately treated using USGS maps because of the limitations imposed by their wetland classification.

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