AN ANALYSIS OF FISH ASSOCIATIONS IN TENNESSEE AND CUMBERLAND DRAINAGE IMPOUNDMENTS

THOMAS A. McDONOUGH, Fisheries and Waterfowl Resources Branch, Division of Forestry, Fisheries, and Wildlife Development, TVA, Norris, TN 37828

WILLIAM C. BARR, Fisheries and Waterfowl Resources Branch, Division of Forestry, Fisheries, and Wildlife Development, TVA, Norris, TN 37828

Abstract: Distribution of fish in the heavily impounded Tennessee and Cumberland River systems shows definite longitudinal zonation similar to that in nonimpounded river systems. Ten of 11 physical variables examined were highly correlated with one another, reflecting the complex of conditions accompanying changes from storage reservoirs in upper elevations to mainstream reservoirs in the lowlands. Elevation was the variable most highly correlated with the number of species. Cluster analysis indicated 4 associations of reservoirs: lower mainstream, upper mainstream and large storage, upper Holston, and Blue Ridge.

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Streams and rivers change longitudinally in a fairly predictable manner with respect to properties such as volume, velocity, current spread, substrate, and turbidity (Reid 1961, Hynes 1970). As a result, the biota of flowing waters, including fish, display longitudinal zonation (Shelford 1911, Burton and Odum 1945, Minkley 1963, and Harrel et al. 1967, and others). During the past half century, however, many rivers have been impounded to provide recreational waters, flood control, hydroelectric power, and improve navigation. Following impoundment, the habitat is altered so that many of the original species are replaced by fishes that are characteristic of the sluggish lentic reaches of the river (Swingle 1954, Hall 1955). Reservoirs, therefore, offer a unique situation: an originally pronounced environmental gradient is altered to create conditions for which many of the original inhabitants are unsuited, and new niches are created which few of these species are able to fill.

The objectives of this study were to see if longitudinal zonation persists among the reservoirs of a major reservoir system, to determine if fish associations are apparent from an analysis of species occurrence data in reservoirs, and to examine relations of these associations to the physical characteristics of the individual reservoirs in the system.

MATERIALS AND METHODS

Data on the presence or absence of fish species in reservoirs were obtained from summer cove rotenone samples made by Tennessee Valley Authority (TVA) fishery biologists. Collection and treatment of data followed methods standardized throughout the southeastern United States (Hall 1974).

To examine the relationship of species within reservoirs, we generated a matrix of coefficients of association, based on presence or absence of fish species in each of 21 reservoirs. The coefficient of association used was the Jaccard coefficient (S_j) (Jaccard 1908):

$$a/(a+b+c) = S_j \qquad (1)$$

where *a* is the number of species in the study occurring in both of the reservoirs, *b* is the number of species occurring in reservoir 1, but not reservoir 2, *c* is the number of species in reservoir 2, but not reservoir 1. Although this coefficient was developed to clarify similarities of plant associations from different quadrats in an alpine ecosystem, similar analyses have been made on other botanical environs (Sorenson 1948) and animal assemblages (Hershkovitz 1958, Long 1963).

Noninclusion of negative matches is an important characteristic of the Jaccard coeffiicent. Hence, if a fish species is found in one or more of the reservoirs in the system but not in the 2 specific reservoirs (i and j) being compared, it would not contribute to the coefficient of association for the reservoirs. Many non-Jaccardian coefficients do not have this feature (Cairns and Kaesler 1969, Sneath and Sokal 1973).

Species were included in the analysis if they occurred in at least 10 percent of the samples from a given reservoir. This minimized the effect of the differences in the number of samples between reservoirs. It also excluded from consideration most species not considered typical reservoir inhabitants and questionable identifications.

The matrix of coefficients of association were subjected to cluster analysis using an unweighted pair-group method (Sneath and Sokal 1973). A matrix of correlation coefficients between several physical reservoir characteristics and fish species was developed using TVA limnological data from STORET and TVA fisheries records. The physical features selected were:

(1) drainage area (km^2)—area above the dam from which surface runoff normally drains; (2) area of reservoir (ha)—measured at mean annual pool; (3) elevation (m)—height above mean sea level at mean annual pool; (4) latitude; (5) water level fluctuation (m)—mean annual vertical fluctuation of surface level; (6) total dissolved solids (ppm)—total residue upon evaporation at 180 C (mean of 1973 and 1974); (7) mean depth (m)—measured at mean annual pool; (8) storage ratio—ratio of reservoir volume to mean annual discharge; (9) growing season (days)—annual number of consecutive frost-free days; (10) temperature (C)—mean of weekly readings for 1973-1974; and (11) flow (ft^3/sec)—mean of weekly readings 1973-1974 measured at the dam.

RESULTS AND DISCUSSION

A total of 82 fish species (Table 1) qualified for analysis, i.e., occurred in 10 percent or more of the samples in one or more of the 21 reservoirs (Fig. 1). The distribution

Table 1. List of fish species occurring in 10 percent or more of population samples in 21 Tennessee and Cumberland drainage reservoirs

Species	*Barkley*	*Old Hickory*	*Kentucky*	*Pickwick*	*Wheeler*	*Guntersville*	*Nickajack*	*Chickamauga*	*Watts Bar*	*Fort Loudoun*	*Melton Hill*	*Norris*	*Cherokee*	*Douglas*	*Tims Ford*	*Boone*	*South Holston*	*Watauga*	*Fontana*	*Chatuge*	*Motely*
Cyprinus carpio	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ictalurus punctatus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lepomis macrochirus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Micropterus salmoides	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dorosoma cepedianum	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x
Dorosoma petenense	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x			x
Notropis galacturus			x	x		x	x		x		x		x	x		x	x	x	x	x	x
Pylodictis olivaris	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x
Lepomis gulosus	x	x	x	x	x	x		x	x	x	x		x	x	x	x	x			x	x
Lepomis auritus	x						x		x	x	x		x	x					x	x	x
Lepomis cyanellus	x	x	x	x	x	x	x	x							x	x			x		x
Notemigonus crysoleucas	x	x	x	x	x	x	x	x			x				x	x	x	x	x	x	x
Micropterus punctulatus	x	x	x	x	x	x		x	x	x	x	x	x		x						x
Pomoxis nigromaculatus	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Perca flavescens							x	x			x	x	x	x		x	x	x	x	x	x
Pomoxis annularis	x	x	x	x	x	x	x	x	x	x										x	x
Notropis atherinoides	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	
Notropis whipplei	x	x					x		x		x	x	x		x		x	x		x	
Ictalurus natalis	x	x		x		x	x			x	x		x		x	x	x	x		x	
Morone chrysops	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	
Lepomis microlophus	x		x	x	x	x	x	x	x		x				x	x				x	
Micropterus dolomieui			x	x	x				x	x	x	x	x		x	x	x	x	x	x	
Ictalurus nebulosus	x	x	x	x			x													x	
Ictalurus melas	x	x			x	x														x	
Hypentelium nigricans	x			x	x			x	x		x		x		x	x	x	x	x		
Stizostedion vitreum	x											x						x	x		
Campostoma anomalum		x	x	x	x			x			x	x	x	x	x	x		x	x		
Moxostoma macrolepidotum			x	x				x	x	x	x	x		x			x	x	x		
Ambloplites rupestris							x					x			x			x	x		
Carassius auratus						x				x	x		x	x	x	x	x	x			
Moxostoma erythurum	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x			
Pimephales notatus	x		x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x		
Moxostoma duquesnei				x	x			x	x		x	x	x	x		x	x	x			
Percina caprodes	x	x	x	x	x	x	x	x	x	x	x		x				x	x			
Labidesthes sicculus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Moxostoma carinatum				x	x			x			x	x	x		x			x			
Notropis spilopterus	x	x	x	x	x	x		x									x	x			
Pimephales promelas	x		x	x		x			x		x	x	x		x		x				
Pimephales vigilax	x	x	x	x	x	x		x		x	x						x				

Table 1. (Continued)

Species	*Barkley*	*Old Hickory*	*Kentucky*	*Pickwick*	*Wheeler*	*Guntersville*	*Nickajack*	*Chickamauga*	*Watts Bar*	*Fort Loudoun*	*Melton Hill*	*Norris*	*Cherokee*	*Douglas*	*Tims Ford*	*Boone*	*South Holston*	*Watauga*	*Fontana*	*Chatuge*	*Motely*
Carpiodes cyprinus	x	x						x			x	x	x			x	x				
Lepomis gibbosus											x		x	x		x	x				
Catostomus commersoni	x																x				
Lepomis megalotis	x	x	x	x	x	x	x	x	x	x	x						x				
Stizostedion canadense	x	x	x	x	x	x		x	x	x	x					x					
Aplodinotus grunniens	x	x	x	x	x	x	x	x	x	x	x	x			x	x					
Ictiobus bubalus	x	x	x	x	x	x	x	x	x	x	x	x		x	x						
Carpiodes carpio	x	x	x			x			x		x	x	x	x	x						
Minytrema melanops	x	x	x	x	x	x	x	x	x		x			x	x						
Hiodon tergisus	x	x	x	x	x	x	x	x	x		x		x	x	x						
Lepisosteus oculatus	x		x	x	x	x		x	x						x						
Gambusia affinis	x	x	x	x	x	x						x		x							
Lepisosteus osseus	x	x	x	x	x	x	x	x	x					x							
Morone saxatilis											x		x								
Alosa chrysochloris	x	x	x	x	x	x	x	x	x	x		x	x								
Ictiobus niger	x	x						x					x								
Moxostoma enisurum					x						x										
Carpiodes velifer	x										x										
Cottus carolinae											x										
Hybopsis storeiana	x	x		x	x	x	x	x		x	x										
Fundulus notatus		x	x	x	x	x				x	x										
Ictalurus furcatus			x	x				x		x											
Notropis photogenis									x												
Morone mississippiensis	x		x	x	x	x	x	x													
Lepomis humilis	x	x	x	x	x	x	x	x													
Ictiobus cyprinellus	x	x	x	x	x			x													
Fundulus olivaceus	x	x		x	x			x													
Lepisosteus platostomus	x		x	x	x	x	x														
Etheostoma flabellare				x	x																
Etheostoma kennicotti				x	x																
Notropis volucellus				x																	
Notropis chrysophalus				x																	
Noturus gyrinus	x			x																	
Etheostoma caeruleum	x		x	x																	
Hybopsis amblops			x																		
Polyodon spathula	x	x																			
Fundulus catenatus		x																			
Esox niger	x																				
Focomos micropogon	x																				
Notropis emiliae	x																				
Aphredoderus sayanus	x																				
Etheostoma asprigene	x																				
Percina schumardi	x																				
TOTAL NUMBER	60	44	47	56	48	43	36	45	37	31											

of fish species showed distinct longitudinal zonation, with the reservoirs in the higher elevations being made up of the relatively ubiquitous species, and an increase in the number of species downstream (Table 1 and Fig. 2).

The matrix diagram (Fig. 3) shows the degree of similarity (S_j) of species composition (probability > 0.10) between populations of each reservoir pair. The Jaccard coefficients were subjected to cluster analysis using the unweighted pair-group method and presented as a dendrogram (Fig. 4). Four associations are apparent based on within-group average Jaccard coefficients. The analysis tends to group reservoirs located at similar elevations, indicating that the complex of conditions correlating with elevation (Table 2) is of importance. Adjacent reservoirs on the same river or on neighboring tributaries also tended to have similar populations.

Reservoir association complex I (Fig. 4) is located on the lower reaches of the Tennessee and Cumberland Rivers. These 2 river systems are connected by a canal between Barkley and Kentucky Reservoirs. All the reservoirs in association complex I

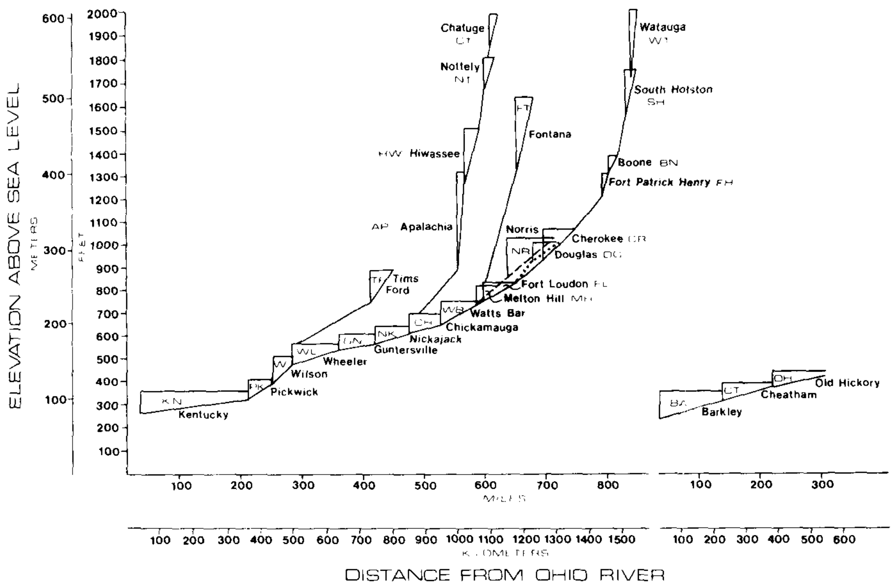

Fig. 1. Longitudinal profile of Tennessee and Cumberland drainage systems showing relative location and elevation of major impoundments.

have navigational locks that permit some movement of fish up and down the systems. The storage ratio of reservoirs in complex I is less than 0.035, and their lake elevations (meters above mean sea level at mean annual pool) vary between 108 m (Barkley) and 208 m (Chickamauga).

The second association group (II) includes Watts Bar and Fort Loudoun Reservoirs on the Tennessee mainstream along with the larger storage reservoirs. Many of these reservoirs, especially Watts Bar and Fort Loudoun, show close resemblance with the reservoirs in complex I, Fig. 3, indicating intergradation between the 2 groups. Reservoir storage ratios are greater than 0.035. Mean annual reservoir elevation ranged between 226 m (Watts Bar) and 327 m (Cherokee).

The third (III) and fourth (IV) associations are quite similar with respect to both elevation (x > 500m) and storage ratio (x 0.70); however, their geographical locations are quite different. Association complex III is composed of Boone, South Holston, and Watauga Reservoirs, all on tributaries of the Holston River (Fig. 1). This group also shows similarities with many reservoirs in complex II (Fig. 3), indicating some intergradation between groups II and III. Cherokee Reservoir (II), the reservoir immediately downstream of complex III and also on the Holston River, showed the greatest species similarity with group III.

The fourth association (IV), comprised of Fontana, Chatuge, and Nottely Reservoirs, had an average coefficient of association (S) less than the other reservoir groups. Reservoirs within this association were more similar to one another than to reservoirs in other associations in this study despite their locations in widely different drainages. Once again this group showed intergrade effects in that it was similar to complexes II and III (Fig. 3).

To identify those variables which might affect the distribution of fish species, a matrix of correlation coefficients between the number of species (probability > .10) in a reservoir and 11 environmental variables was generated (Table 2). The variable having

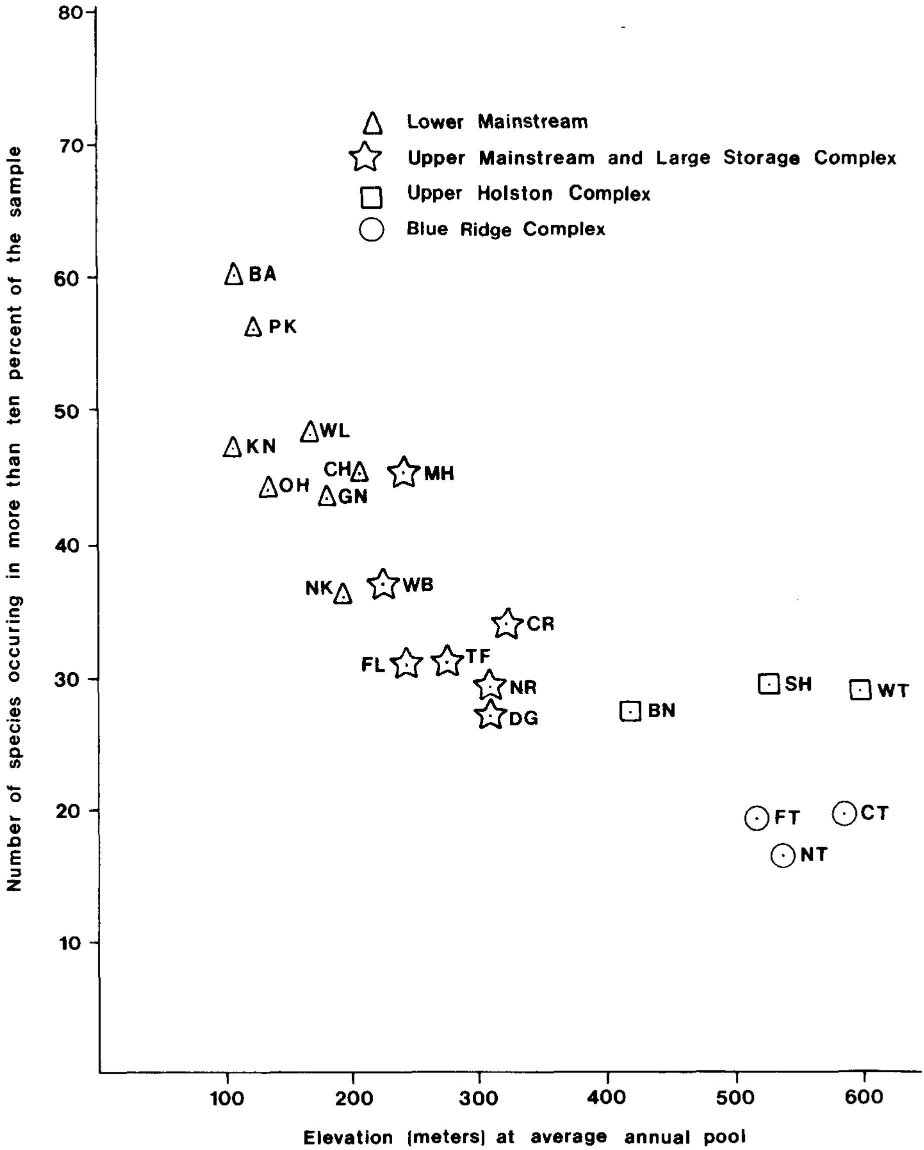

Fig. 2. Plot of the number of species occurring in more than 10 percent of samples versus elevation in meters. The four fish species complexes are indicated by the appropriate symbols.

the highest correlation with the number of species was elevation; however, all variables except latitude were significantly correlated ($P > .01$). These environmental variables were all highly correlated with each other reflecting general differences in storage reservoirs in the mountains and mainstream impoundment in the lowlands. Other workers have related many of these same variables to fish biomass (Jenkins 1968, Ryder 1965) and have found mean depth and total dissolved solids to be the best predictors of fish standing stock.

	Kentucky	Guntersville	Pickwick	Wheeler	Chickamauga	Barkley	Old Hickory	Nickajack	Watts Bar	Douglas	Melton Hill	Cherokee	Fort Loudon	Norris	Tims Ford	Boone	South Holston	Watauga	Fontana	Nottely	Chatuge
Kentucky	1.00																				
Guntersville	.77	1.00																			
Pickwick	.78	.68	1.00																		
Wheeler	.70	.72	.79	1.00																	
Chickamauga	.67	.63	.71	.76	1.00																
Barkley	.60	.64	.61	.59	.59	1.00															
Old Hickory	.63	.67	.59	.64	.65	.65	1.00														
Nickajack	.57	.65	.53	.53	.56	.52	.54	1.00													
Watts Bar	.61	.60	.55	.54	.58	.49	.47	.55	1.00												
Douglas	.48	.49	.38	.39	.47	.36	.42	.43	.60	1.00											
Melton Hill	.53	.57	.51	.53	.53	.54	.53	.42	.61	.50	1.00										
Cherokee	.47	.51	.45	.46	.46	.42	.50	.43	.58	.56	.65	1.00									
Fort Loudon	.53	.57	.50	.49	.52	.40	.50	.49	.54	.53	.55	.51	1.00								
Norris	.52	.47	.44	.48	.51	.39	.49	.48	.57	.51	.48	.58	.54	1.00							
Tims Ford	.48	.52	.43	.47	.47	.41	.51	.50	.52	.43	.53	.56	.49	.51	1.00						
Boone	.42	.46	.41	.41	.44	.36	.39	.43	.42	.50	.53	.56	.49	.44	.54	1.00					
South Holston	.38	.41	.42	.37	.42	.33	.35	.35	.47	.47	.54	.62	.46	.45	.44	.60	1.00				
Watauga	.34	.34	.38	.36	.38	.29	.31	.42	.44	.45	.46	.55	.44	.54	.49	.53	.63	1.00			
Fontana	.29	.24	.27	.26	.28	.21	.24	.34	.33	.39	.31	.36	.35	.41	.36	.48	.41	.52	1.00		
Nottely	.29	.31	.24	.26	.30	.23	.28	.37	.33	.39	.27	.35	.38	.29	.31	.39	.36	.33	.52	1.00	
Chatuge	.27	.29	.25	.24	.23	.25	.29	.41	.33	.31	.36	.36	.35	.26	.32	.44	.37	.34	.41	.46	1.00

- > .70
- .60 - .70
- .50 - .60
- .40 - .50
- < .40

Fig. 3. Matrix diagram of Jaccard coefficients of an association between pairs of reservoirs. The shading above the diagonal indicates intervals of .10 increments of similarity.

Latitude was not significantly correlated ($P < .05$) with any of the other variables. This probably results from the east-west orientation of the Tennessee and Cumberland Rivers. Both systems arise at about 37° N latitude, flowing southwesterly to about 34° 30' N latitude. and 35° 45' N latitude, respectively, and thence northwesterly to their confluence with the Ohio at approximately 37° N latitude.

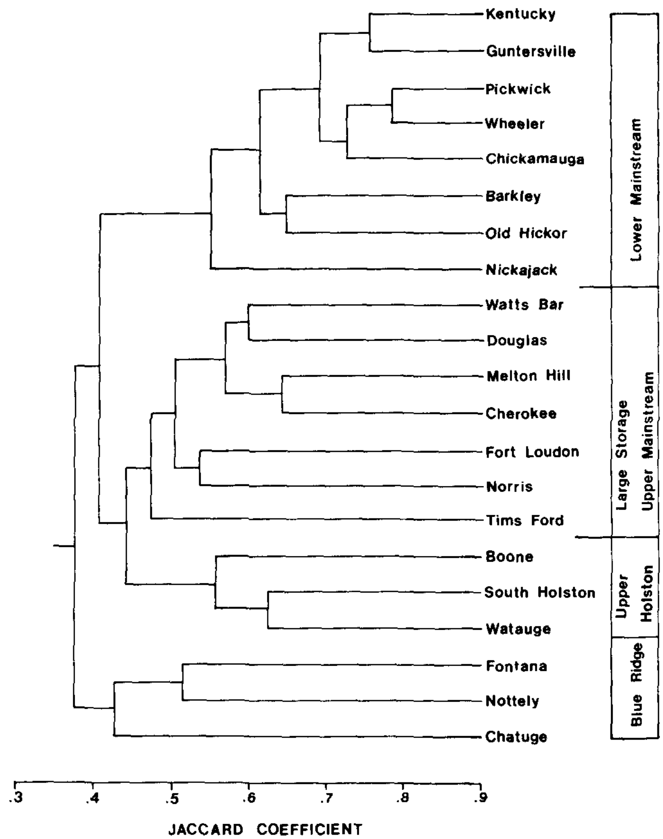

Fig. 4. Dendogram of Jaccard coefficients showing the fish species association in 21 Southeastern reservoirs.

The reservoirs with the largest fish species assemblages (Fig. 2) are nearest the mouth of the system, with a general tendency toward presence of smaller species assemblages in reservoirs nearer the headwaters. The grouping of reservoirs into complexes I-IV does not change this trend. There were 24 fish species which were ubiquitous, occurring in at least 1 reservoir in each group; 12 species which were found in all but group IV; 17 found only in groups I and II; and 20 fish species unique to group I (Table 1). The intergradation between areas indicates that the groups defined by cluster analysis may be artificial; it may be more appropriate to describe reservoir fish associations as a continuum along a longitudinal gradient.

The presence of such a gradient is not surprising. Studies on longitudinal zonation in streams and rivers are common (see Hynes 1970, Reid 1961 for review). These studies all showed that the number of stream species tends to vary directly with characteristics such as drainage area, flow, pool depth, and width; and inversely with elevation and gradient. In streams this increase in the number of fish species has been attributed to an increase in available habitat and a decrease in environmental fluctuation (Harrel, et al. 1967). Since the original riverine fish species became the initial reservoir population following impoundment, these conditions would be expected to persist.

In addition to having greater total numbers of species, the fish species present in the lower reaches of a system tend to be better adapted for the lentic condition created by impoundment (Table 1). It would, therefore, be expected that the lower reaches of a river would contain more species able to survive in a reservoir. Therefore, the impoundments on the tributary rivers may contain fewer species because there were fewer species present in the river before impoundment which are suitable for surviving in the reservoir.

SUMMARY

1. In the heavily impounded Tennessee River system longitudinal zonation of fish species occurs in a manner similar to unimpounded rivers and streams.
2. Cluster analysis of the fish species data showed 4 associations: Lower mainstream (I), upper mainstream and large storage (II), upper Holston (III), and Blue Ridge (IV).
3. Native fish species present in groups III and IV are generally present throughout the system, with additional species being found downstream.
4. All physical variables considered, with the exception of latitude, were significantly correlated ($P > .01$) with the number of species.
5. The highest correlation of fish species with a physical variable was with elevation where a correlation coefficient was present of -0.85.

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