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AN ENVIRONMENTAL STUDY OF THE ORIGIN, DISTRIBUTION,
AND BIOACCUMULATION OF SELENIUM IN KENTUCKY AND
BARKLEY LAKES

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ABSTRACT

Many samples of water, bottom sediment, and fish were analyzed for toxic metal ion content. The samples were collected from several selected sites along Kentucky and Barkley Lakes as well as the Cumberland River and several sub-impoundments along these aquatic systems. Emphasis was placed on selenium, although several other metal ions were determined. The results showed that there are no serious pollution problems with As, Cd, Cr, Cu, Hg, Pb, Se, Sr, Zn, or Zr at any of the sites examined. Actually, none of the trace metals examined even come close to the EPA limits on fish, with the exception of lead in the White Crappie and mercury in the Bass. There appears to be no serious problem with lead in White Crappie as only two fish out of a total of nineteen were above the limit of 2 PPM. The same holds for mercury in the bass as only three fish out of thirty-four were above the 0.5 PPM level. Water and sediment analyses for the above mentioned metal ions fell well within expected "normal" limits for unpolluted fresh water systems. No point sources could be identified for any of the metal ions. This is in contrast with results obtained on the lower Tennessee River by Hancock, et al, in which a large chemical complex was found to contribute significant quantities of trace metals. No significant seasonal variation of trace element content was observed in any of the sample types. Since the selenium content of all samples was so low, no laboratory bioaccumulation data were obtained. No general correlation between fish length and trace element content could be established, although there was a relationship for some elements, usually positive but sometimes negative. There was some correlation between trace element

content and area and between elemental content and species of fish. However, these relationships are complex and depend on the trace element studied. The most important conclusion to be drawn from this study is that at this time there appears to be little problem with trace metal pollution in Kentucky and Barkley Lakes.

Descriptors: Trace Elements*, Deposition (Sediments), Water Quality,
Chemical Analysis

Identifiers: Atomic Absorption Spectrometry, Bioaccumulation

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CHAPTER I

INTRODUCTION

This study was undertaken with two major objectives in mind. The first being to determine if there was any kind of metal ion pollution problem present in the Kentucky and Barkley Lakes area, and to make an attempt to determine possible sources if any pollution problems were found. The second goal was to provide some background levels for a number of metal ions in several species of fish from this area. This is important since little work has been done on metal ion contamination of freshwater fishes, especially warm water fishes.

These two objectives have necessitated that a broad area be covered in the sampling and analysis for the study. A number of different metals had to be determined in each of several species of fish. In order to get some idea of possible sources of contamination, if any problems were found, it was necessary to analyze fish from a number of different sites.

The fact that this study is spread over such a wide area has led to several problems when trying to analyze the final data. Even though a large number of samples were analyzed, when the data is broken down to individual metals, species, and areas, the sample sizes are as small that most statistical analysis is not very meaningful. An attempt has been made to identify as many trends and patterns as possible within the data, using as many tests as possible under the circumstances.

Another problem that has arisen involves minimum detection limits. For many of the metals there was a percent of the fish tested that showed metal concentrations below the minimum detection limits of the instruments

used. Therefore, no values could be determined for these fish, and they could not be used in any of the calculations. As a result of this, all graphs and statistical analyses are based only on the fish that were above the detection limit. In Figures I through IX, the number of samples that the graphs are based on are indicated above the individual graphs. Right below these numbers, in brackets, is the number of fish run that were below detection limits and, therefore, not used in the calculations for the graphs.

Since the selenium levels in all samples of water, bottom sediment and fish were so low, it was deemed unnecessary to acquire bioaccumulation data under laboratory conditions. Also, the Bass are at the top of the food chain in the aquatic systems studied and would show the highest levels of selenium if it were present at significant levels. Quite normal levels of selenium were found in all fish samples analyzed, therefore, it was decided to acquire data on other toxic metal ions on samples from the aquatic systems as the samples were already available.

CHAPTER II

RESEARCH PROCEDURES

A. Apparatus

All analytical measurements were made using either hydride generation or furnace atomic absorption (AA) spectrometry. A modified Jarrell-Ash Model 82-500 AA instrument was used for hydride generation methods. The Perkin-Elmer Model 603 combined with the HGA-2200 furnace was used for furnace AA measurements. Both H_2 flame and heated-cell hydride generation techniques were employed for selenium determinations.

B. Procedures

Water, bottom sediment, and fish samples were taken at selected sites from Kentucky and Barkley Lakes as well as from several other impoundments and streams in western Kentucky (See Map 1). Water samples were collected with a Kemmerer sampler. It was of PVC construction and can be used for collections at any depth. Bottom sediment was collected with either an Ekman or Ponar dredge. Fish were collected with gill nets or by the electroshocking technique. Water samples were stabilized by addition of 3% HNO_3 and refrigerated until they were analyzed. Bottom sediments were stored in plastic containers and refrigerated until analysis. The fish samples were filleted and the samples kept frozen until analyzed.

The water samples were analyzed directly by furnace or hydride generation atomic absorption spectrometry without sample pre-treatment. The bottom sediment and fish flesh samples (~ 1 g) were wet ashed with a mixture of 5 ml conc. HNO_3 and 5 ml 30% H_2O_2 under reflux conditions to

avoid loss of volatile elements. Reflux heating was done for about 1 hour or until the sample was dissolved. The solution was allowed to cool and the column was rinsed with deionized water. The solution was diluted to 100 ml with deionized water. A clear solution should be obtained at this point for the fish samples. For bottom sediments, insoluble silicates must be removed by filtration. Once the sample was in solution, selenium and arsenic were determined by hydride generation atomic absorption, mercury was determined by cold-vapor AA, zinc by flame AA, and the remainder of the elements by furnace AA. Once the data were acquired, standard graphical and statistical methods were used to treat and present the data.

CHAPTER III

DATA AND RESULTS

Table 1 shows the total number of fish tested for each metal and the percent of this number that were below the detection limit, as well as the lowest concentration that was detected for each metal. Since a curve fitting program for linear regression was used to establish the calibration curves from the standards, and this line was in turn, used to determine solution concentrations from each reading, it was hard to determine a true minimum detection limit. By using this technique it was sometimes possible to get extrapolated concentration values that fell between the blank and the lowest standard used. Therefore, the minimum detection values listed in this table are the lowest positive concentration values that were calculated for each metal.

In most cases the number of fish below the detection limit is a small percent of the total number and should have little bearing on the results. However, for lead and strontium the percent of fish below the detection limit make up a large percent of the total. For lead 73.8% of the fish analyzed were below the detection limit and for strontium 41.7%. For strontium the sample size is small to start with so this adds to the problem. For these two metals any graphs or other statistical analyses are of questionable value at best, and can just be used to point out some very general trends.

Even with these problems, the results of this study have fulfilled the major objectives set down at the start. An attempt will be made to point out individual points and trends as the data is analyzed. There is

one major trend that shows up throughout the analyses; that being the fact that there appears to be no major pollution problem with any of the metal ions examined for any species or in any area.

A. Metal Ion Analysis in Water

A number of water samples were collected as an initial part of this study. These samples were collected from a number of different sites, including not only the main fish sampling areas, but also several sites along the Cumberland River and several other smaller river systems in western Kentucky and northwestern Tennessee. The analysis of these samples provided an opportunity to become familiar with the instruments and to work on the individual techniques needed for the different metal ions. These samples also provided some good background information on the levels of the different metal ions present in the surface water of the area.

Initial plans were to break these water data down by areas, but after looking at the data it became apparent that there was not enough variation between areas to show any differences. Doing this would have also resulted in very small sample sizes for some areas. For this reason, all the water data have been grouped and examined together. Table 2 shows the results of these analyses. There was not a single value for any metal ion that exceeded the EPA standards set for domestic water. Chromium and copper each had one sample that approached these standards, but the means for even these two metals were well below the standards. The only place where there was any conflict with the standards was in cadmium where one sample exceeded the 1.2 PPB maximum standard established for salmonid fish. This one sample is much higher than the next highest cadmium concentration level found which was only 0.99 PPB. This

high sample came from Donaldson Bay on Barkley Lake. A second sample taken the same day in the main reservoir at the mouth of Donaldson Bay had a concentration of 0.92 PPB. A water sample taken from Donaldson Bay at a later date only showed a cadmium concentration of 0.45 PPB. The fact that this one sample was so far above the rest of the samples leads to speculation that the sample may have been contaminated. Although it should not be completely disregarded, neither should this one sample be taken as a strong indication of cadmium contamination. The fish samples that were analyzed from this area gave no indication of a cadmium problem. A large number of water samples from many different areas were analyzed for selenium. Of 113 samples from throughout western Kentucky and north-west Tennessee, only five samples were used to compute the mean in Table 2, so this mean is not a good representation of the selenium levels in the area. These five samples were randomly distributed from throughout the sampling areas so that there is no indication of a point source of selenium.

Lead, mercury, and zirconium are not included in Table 2 because of earlier work that showed Kentucky and Barkley Lake water to be very low in lead (McClellan and Vargo, unpublished data), and because of the small percent of fish showing detectable levels of lead, no attempt was made to run water samples for lead. Twenty water samples were run for zirconium with none of them showing levels above the minimum detection limit of 10 PPM. While trying to establish a standard curve for mercury, it was discovered that there was a significant decrease in the mercury levels of low concentration standards after just sitting covered for a couple of hours. Since most of the water samples had been in the refrigerator for a month or more before mercury analysis was begun, it was decided that

any mercury that had been present in the water samples would have been lost making analysis of the samples meaningless. Therefore, no water was analyzed for mercury.

B. Metal Ion Analyses in Fish Samples

The initial phase of analysis of the fish data consists of a comparison between areas by species for each metal. It was hoped that by breaking down the results in this way, it might provide a better insight into possible sources of pollution if a problem did exist. The Donaldson Bay and Anderson Bay samples provide a direct comparison between mainstream Barkley and Kentucky Lakes. By comparing the Barkley Lake sub-impoundments with their associated mainstream bays, it was hoped that some insight could be gained as to whether a contamination problem was of local origin or was coming down the main river system. Because of the small sample sizes and the rather large variations within these samples when the data is broken down this far, it was difficult to find any clear patterns for any metal ions. If a pattern did start to show up in one species it was usually contradicted by a different species. Figures I through VII show the calculated mean, standard error, and ranges for each metal ion broken down by area and species. The maximum permissible levels of each metal in fish are indicated on the graphs if standards have been established and if they are within the range of the graph. The number of fish found with metal ion concentrations above these levels are also indicated on the graphs.

A MSU STAT program at the University of Montana in Bozeman entitled ANOV1 was used to run an analysis of variance between individual areas for each species and metal ion using just the values that were above the detection limits (Lund 1969). There were only four

instances where there was any significant differences at the 0.05 level between any areas. These cases will be mentioned in the individual discussions below.

1. Individual Metals by Species and Area

There were only three metals for which any fish showed levels above the maximum permissible standards established by the National Health and Medical Research Council for seafood (Bebbington, et al. 1977). These were lead, copper, and cadmium. Lead had two fish over the standard and copper and cadmium each had one. This is only 2.4% of the fish tested for lead and less than 1% of the fish tested for copper and cadmium.

Figure I shows the breakdown for lead by areas. As mentioned before 73.8% of the fish tested for lead were below the minimum detection limits, so it isn't advisable to make any strong statements about the remaining data. Looking at the graph, it is possible to make a couple of tentative observations. First it appears that crappie show the highest accumulation of lead of any of the species. Both of the fish that were above the 2 PPM standard were crappie. Both of these fish were just slightly above the standard, and it should be noted that in the case of Anderson Bay, the other two fish run from this same area had lead concentrations below the detection limit. The crappie also had the highest percent of the fish tested for any species showing lead levels above the detection limit. It is tempting to speculate from this graph that the lead levels might be higher in the Honker Lake, Honker Bay area than elsewhere, but it would be dangerous to make such a statement based on the small sample size available.

Figure II shows the breakdown of copper by area and species. The one fish that was above the copper standard of 30 PPM was a drum from Crooked

Creek Bay. Again, this fish was just slightly above the standard with no other fish even coming close. An analysis of variance of this data indicated there were no significant differences between any species for any areas. There are two trends that do show up and might become significant if the sample size was increased. For all four species, Anderson Bay, the mainstream Kentucky Lake sample, was higher than the mainstream Barkley Lake sample from Donaldson Bay. In all cases except the Crooked Creek Bay drum, Anderson Bay had the highest mean of any area. This may indicate that copper is higher in Kentucky Lake than in Barkley Lake or its sub-impoundments. In looking at just the Barkley Lake system, the copper concentration in channel catfish, bass, and drum from the Barkley Lake bays are always higher than their associated sub-impoundments. This may be an indication that the copper present is coming from up river rather than from local sources. Crappie, on the other hand, do not fit this pattern for Energy Lake or Honker Lake.

It can be seen from Figure III that one channel catfish from Crooked Creek was just slightly above the maximum standard of 2 PPM for cadmium. There was only one other fish out of the 120 that were run for cadmium that had a concentration above 500 PPB. Most of these fish showed cadmium concentrations less than 100 PPB. Here again the exposure of this data to analysis of variance indicated that there were no significant differences between any of the areas for any species. Looking over the graph there are no general trends that can be mentioned.

Looking at Figure IV it is apparent that there is very little difference in zinc levels between any areas for any species. Not one of the fish analyzed contained even one-tenth of the maximum allowable level of 1000 PPM. Again there were no significant differences between

any areas at the 0.05 level. It appears that there should be a significant difference between the drum from Crooked Creek and Energy Lake, but this did not show up in the analysis of variance test. This is probably due to the large standard errors for the two areas and the small sample sizes resulting when the data is broken down this way. The means are almost identical between these two areas for the other three species.

Figure V shows a lot more variation between areas for chromium, but there is also a lot more variation between individual fish within the areas. This results in larger standard errors with more overlap. Again the analysis of variance test did not show any significant differences between any areas. There have been no maximum standards established for chromium in fish or seafood. It is known that chromium (III) is a required trace element in small amounts. Only four fish out of the 134 tested showed chromium levels above 1 PPM, with only one of these going just over 2 PPM. It is therefore, doubtful that there is any reason for concern about chromium contamination in the fish of this area. There are no trends or patterns that show up and hold for all four species.

Mercury and selenium were the only two metals where the analysis of variance indicated there were significant differences between areas for the species. Mercury showed significant differences for catfish and drum, selenium for bass and drum. In these cases where a significant difference was indicated, the MSUSTAT program COMPARE was used to run multiple range comparisons between each pair of areas for the group (Lund, 1979).

Figure VI shows that there is quite a bit of variation between areas for mercury. The COMPARE program showed Anderson Bay to be significantly higher than Energy Lake, Honker Bay, or Bards Lake, and that

Bards Bay was significantly higher than all the other areas except Anderson Bay for catfish. It also showed Anderson Bay and Crooked Creek were significantly higher than the other areas for drum. None of these trends follow through for the other species as they probably have little value in the overall analysis. Anderson Bay does show up rather high in three of the four species which might indicate that mercury is more prevalent in Kentucky Lake than in Barkley, but it would not be advisable to make any definite statements along these lines based on these data. When this study was started the maximum allowable level for mercury in fish was 0.5 PPM. Just recently this standard has been increased to 1 PPM. There were three fish that showed mercury concentrations above the old standard of 0.5 PPM, but none are above the new standard. The three fish that exceeded this old standard were all bass. This is 8.8% of the bass tested. It is well known that mercury is accumulated through the food chain. Since bass are the top predator in this aquatic ecosystem, it would be expected that they would show the highest levels of mercury. Although the standards have been changed, these levels should be high enough to merit future monitoring of mercury in bass of this area.

Crooked Creek Bay is quite a bit higher in mercury than Energy Lake for three of the four species. For crappie, Energy Lake is slightly higher, but there is really no difference between these two areas here. Bards Bay is also higher than Bards Lake for the three species where data is available. Honker Lake and Honker Bay reverse this trend with the lakes being higher than their associated bays for two species, but again there is very little difference in either case here. This might be enough evidence to indicate that mercury is in the main river system and not coming from local sources.

Selenium also showed significant differences between some of the areas for two species when subjected to analysis of variance. Here again, the patterns established are not even consistent between these two species, let alone holding for all four species. Looking at Figure VII, it can be seen that there are no trends or patterns that show up for all species. There are only seven fish that showed selenium levels greater than 500 PPB with the highest concentration found being 818 PPB. This is well below the maximum allowable level of 2 PPM established by the National Health and Medical Research Council (Bebbington, et al. 1977).

There are three other metal ions that were looked at in this study for which not enough data was collected to make it possible to graph the results. These were strontium, arsenic, and zirconium.

Three fish of each species from both Energy Lake and Crooked Creek Bay, were run for strontium. As mentioned before, 41.7% of these fish contained levels below the detection limit for strontium. This 41% included fish from all species and areas so that it was not possible to get any usable comparisons between the remaining fish. In the 14 fish that were above the detection limit, the strontium concentration ranged from 0.04 up to 851 PPB strontium with a mean concentration of 157 PPB and a large standard error of 70.73. Although this is not a large enough sample to make any comparisons between areas or species, it should be large enough to provide some background levels for strontium in fish for this area, and to show that there is no problem with strontium contamination at this time.

No fish samples were run for arsenic. Quite a bit of time was spent trying to run arsenic in fish, but this work was plagued with an analysis problem. It has been found that arsenic usually shows up higher in the water from an area than in the fish from this water

(Ullman, et al. 1961; Johnson, et al. 1977). Since very little arsenic was found in any of the water samples tested, it was decided not to spend the time trying to work out the analysis problem with the fish samples.

Twenty fish were run for zirconium, but none of them contained levels above the minimum detection limit of 10 PPM zirconium.

2. Comparison Between Species

Figures VIII and IX show a breakdown of each metal ion by species. All of the sample areas have been combined in these graphs. Cadmium, chromium or copper do not show any significant differences between any species, although the drum do seem to show a somewhat higher copper concentration. For both selenium and zinc the drum show significantly greater concentrations of these metals than do the other three species. This is very likely related to the drum's feeding habit, since they rely to a much greater extent on freshwater mussels as a food item than do any of the other species. Since these mussels are filter feeders, and since both selenium and zinc are quite water soluble, they would probably be concentrated to fairly high levels in the mussels. These high levels would then be passed on up the food chain to the drum. Copper is also more soluble than some of the other metals like lead and cadmium and this could explain why the drum are a little higher here too. The bass contain the highest concentrations of mercury which would be expected since they are the top predator and mercury is bio-accumulative. Crappie appear to show a significantly higher concentration of lead than any other species, but as stated before, with greater than 70% of the fish run for lead below the detection limit it would be dangerous to draw any final conclusions from this data.

3. Correlation Between Fish Length and Metal Ion Concentration

An attempt was made to draw some correlation between the total length of the fish and the concentrations of different metals they contained. In general the larger fish that were collected during each sampling period were the ones selected for analysis. It was reasoned that the larger and thus the older fish would probably show the greatest accumulation of any metal and therefore, be the best indicators of any contamination problems.

Table 3 shows the size range and mean size of each species of fish tested for each area. All of these fish were not necessarily run for each metal, but they were all tested for at least some of the metals. Table 4 gives a condensed version of these data with all the areas combined.

Each concentration value was associated with the corresponding total length of the fish involved. These data were then ranked in ascending order by species for each metal and subjected to Spearman's Rho rank correlation test (Conover, 1971). The test hypothesis was that the total length and the associated concentrations were mutually independent, or that there was no correlation between them. The calculated correlation coefficient was compared to table D.24 in Zar (1974) to determine the probability of accepting this hypothesis. For lead only crappie were examined since this was the only species with enough fish above detection limit to make the test meaningful. Table 5 shows the results of this test. There were only four cases where the hypothesis was rejected at the 0.05 level. None of these four showed a strong correlation. In three of these four cases, crappie and drum for copper and drum for selenium, there was a reverse correlation indica-

ting the smaller fish showed the highest concentrations of the metals. There was a small positive correlation between size and concentration for mercury in catfish. These results are not at all what was expected. Especially for metals like mercury that accumulate through the food chain, it would be expected that the larger and older predatory fish would show the greatest concentrations of the metal. These results could be an indication that metals reach an equilibrium level in fish after a certain point, but most of the levels found in this study were so low that it is doubtful that these levels would have been reached even if this were true. More work will have to be done along these lines including more small sized fish before any conclusions can safely be made.

C. Bottom Sediment Analyses

Twenty-four samples of bottom sediment were analyzed for selenium content. The values ranged from 0.11 - 0.59 $\mu\text{g/g}$ selenium with a mean value of 0.32 $\mu\text{g/g}$. Previous workers have reported values of from 0.1 - 2 $\mu\text{g/g}$ in bottom sediment. Values were rather consistent and did not vary greatly from site to site.

CHAPTER IV

CONCLUSIONS

In going through these results and discussions, it has become apparent that there is a lot of data that does not fit together into easily explained patterns. Very few conclusions can be drawn about similarities or differences between different areas or even between different species for any metal. Yet, as a whole, this study has been successful in fulfilling the goals set down at the start. One of the major problems in trying to work with these data has been the low concentration levels encountered for all metals. In reality, these are good results because they have shown that there are no contamination problems present for any of the metals examined for any of the sample areas. This was one of the major goals of the study. Since there were no contamination problems, it was not necessary to try and locate any point pollution sources. Therefore, large differences between areas would not be expected.

Finally, these results present good quantitative data regarding the concentration levels of a number of metals in several species of fish from the study area. These data can be a valuable asset to future studies by providing concentration values on which to base these studies. It will also provide background levels against which future findings can be compared in the case of situations involving the well-being of the environment. This will eliminate one of the major weaknesses found in many of the pollution cases today.

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Table I. Percent of Fish Below Detection Limit

Metal	Number of Fish Analyzed	Number of Fish Below Detection Limit	% Of Total Below Detection Limit	Minimum Detection Limit (PPB)	Lowest Standard Used to Establish Reference Curve (PPB)
Cd	120	8	6.7	0.025	0.05
Cr	134	24	17.9	0.022	1.0
Cu	125	1	0.8	0.45	5.0
Hg	133	7	5.3	0.01 PPM	0.01 PPM
Pb	84	62	73.8	0.74	5.0
Se	101	3	3.0	0.45	2.0
Sr	24	10	41.7	0.08	2.0
Zn	120	0	0	0.025 PPM	0.02 PPM

Table 2. Concentration of Metal Ions in Water Samples

Metal	Sample Size	Mean \pm Standard Error (PPB)	Range (PPB)	EPA Standards
As	21 (1)*	0.59 \pm 0.06	0.17 - 1.30	50 PPB - Water 1.3 PPM for Fish
Cd	31 (8)*	0.52 \pm 0.15	0.01 - 4.6	10 PPB - Water 0.4 PPB for Salmonids
Cr	36 (2)*	3.24 \pm 1.21	0.14 - 41.3	50 PPB - Water 100 PPB for Aquatic Life
Cu	29	19.65 \pm 3.89	2.1 - 90.3	1.0 PPM - Water 0.1 x 96 hr. LC ₅₀ - Aquatic Life
Se	113 (108)*	1.86 \pm 0.51	1.2 - 3.9	10 PPB - Water 0.01 x 96 hr. LC ₅₀ - Aquatic Life
Zn	39 (1)*	20 \pm 2.5	1.0 - 99	5 PPM - Water 0.01 x 96 hr. LC ₅₀ - Aquatic Life
Sr	36 (4)*	0.05 \pm 0.003	0.02 - 0.09	

*Number in brackets below sample size is number of samples below detection limit.

Table 3. Fish Length in MM

		ANDERSON	DONALDSON	ENERGY LAKE	CROOKED CREEK
Channel Catfish	N	9	9	6	6
	$\bar{X} \pm SE$	446.22 \pm 10.51	495.22 \pm 19.31	404.83 \pm 13.33	495.33 \pm 28.47
	SE Range	456.73 - 435.72	514.54 - 475.91	418.16 - 391.5	523.8 - 466.86
	Size Range	390 - 480	425 - 570	362 - 455	424 - 580
Bass	N	7	6	3	3
	$\bar{X} \pm SE$	437.57 \pm 29.94	328.0 \pm 25.01	417.33 \pm 32.16	419.0 \pm 45.54
	SE Range	467.51 - 407.63	353.01 - 302.99	449.5 - 385.17	464.54 - 373.46
	Size Range	310 - 530	409 - 570	355 - 462	355 - 507
White Crappie	N	3	3	6	4
	$\bar{X} \pm SE$	235.33 \pm 2.34	349.3 \pm 26.42	305.33 \pm 19.36	331.75 \pm 5.76
	SE Range	237.67 - 233	375.72 - 322.88	324.69 - 285.97	337.51 - 325.99
	Size Range	231 - 239	320 - 402	215 - 340	317 - 345
Drum	N	7	6	4	6
	$\bar{X} \pm SE$	352.57 \pm 12.12	284.50 \pm 15.64	289.25 \pm 5.50	401.83 \pm 63.65
	SE Range	364.69 - 340.45	300.14 - 268.86	294.75 - 283.75	465.48 - 338.19
	Size Range	262 - 780	251 - 345	278 - 304	480 - 606

Table 3. Fish Length in MM
(continued)

		HONKER LAKE	HONKER BAY	BARDS LAKE	BARDS BAY
Channel Catfish	N	6	9	6	3
	$\bar{X} \pm SE$	449.50 \pm 55.96	460.33 \pm 25.18	423.0 \pm 17.07	494.0 \pm 55.39
	SE Range	505.46 - 393.54	485.52 - 435.15	440.07 - 405.93	549.39 - 438.61
	Size Range	355 - 720	367 - 610	364 - 470	385 - 565
Bass	N		6	3	3
	$\bar{X} \pm SE$		368.67 \pm 20.55	438.0 \pm 28.57	288.0 \pm 58.52
	SE Range		389.22 - 348.12	466.57 - 409.43	346.52 - 229.48
	Size Range		277 - 430	407 - 495	203 - 400
White Crappie	N	6	9	3	3
	$\bar{X} \pm SE$	277.00 \pm 14.70	309.0 \pm 22.93	248.33 \pm 12.99	277.33 \pm 6.18
	SE Range	291.7 - 262.3	331.93 - 286.07	261.33 - 235.34	283.51 - 271.15
	Size Range	216 - 315	216 - 375	229 - 273	265 - 284
Drum	N			3	
	$\bar{X} \pm SE$			301.0 \pm 11.03	
	SE Range			312.03 - 289.97	
	Size Range			283 - 321	

Table 4. Fish Length (mm)

Total For All Fish Combined

	Channel Catfish	Bass	White Crappie	Drum
N	54	31	37	26
\bar{X}	458.04	384.74	295.24	332.54
SE	9.92	14.57	8.55	24.86
SE Range	467.96 - 448.11	399.31 - 370.18	303.79 - 286.69	357.4 - 307.7
Size Range	355 - 720	203 - 570	215 - 402	251 - 780

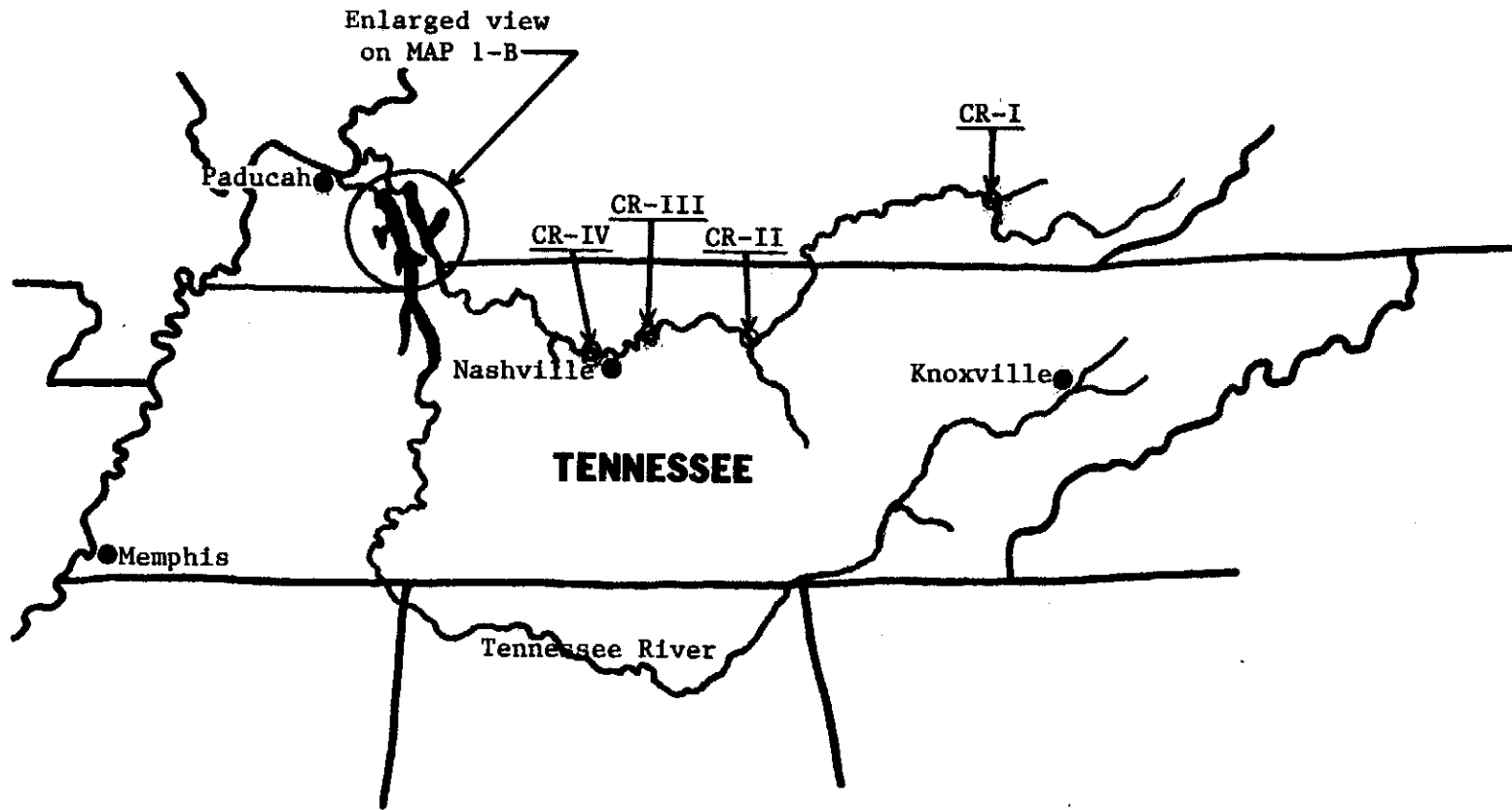
Table 5. Correlation Between Metal Concentrations and Fish Total Length

		Channel Catfish	Bass	Crappie	Drum
Cd	n	36	23	32	20
	r	.001	.114	.062	.010
	p	p < .05	p < .05	p < .05	p < .05
Cr	n	37	25	26	22
	r	.013	.121	.164	.356
	p	p < .05	p < .05	p < .05	p < .05
Cu	n	44	29	31	20
	r	-.154	.243	-.455	-.575
	p	p < .05	p < .05	.02 < p < .01*	.01 < p < .005*
Hg	n	39	31	30	20
	r	.404	.227	.033	-.126
	p	.02 < p < .01*	p < .05	p < .05	p < .05
Pb	n			9	
	r			-.366	
	p			p < .05	
Se	n	30	22	24	22
	r	-.172	-.038	.372	.442
	p	p < .05	p < .05	p < .05	.05 < p < .02*
Zn	n	36	29	34	20
	r	-.129	.296	-.302	.226
	p	p < .05	p < .05	p < .05	p < .05

n = number of fish; r = correlation coefficient; p = probability

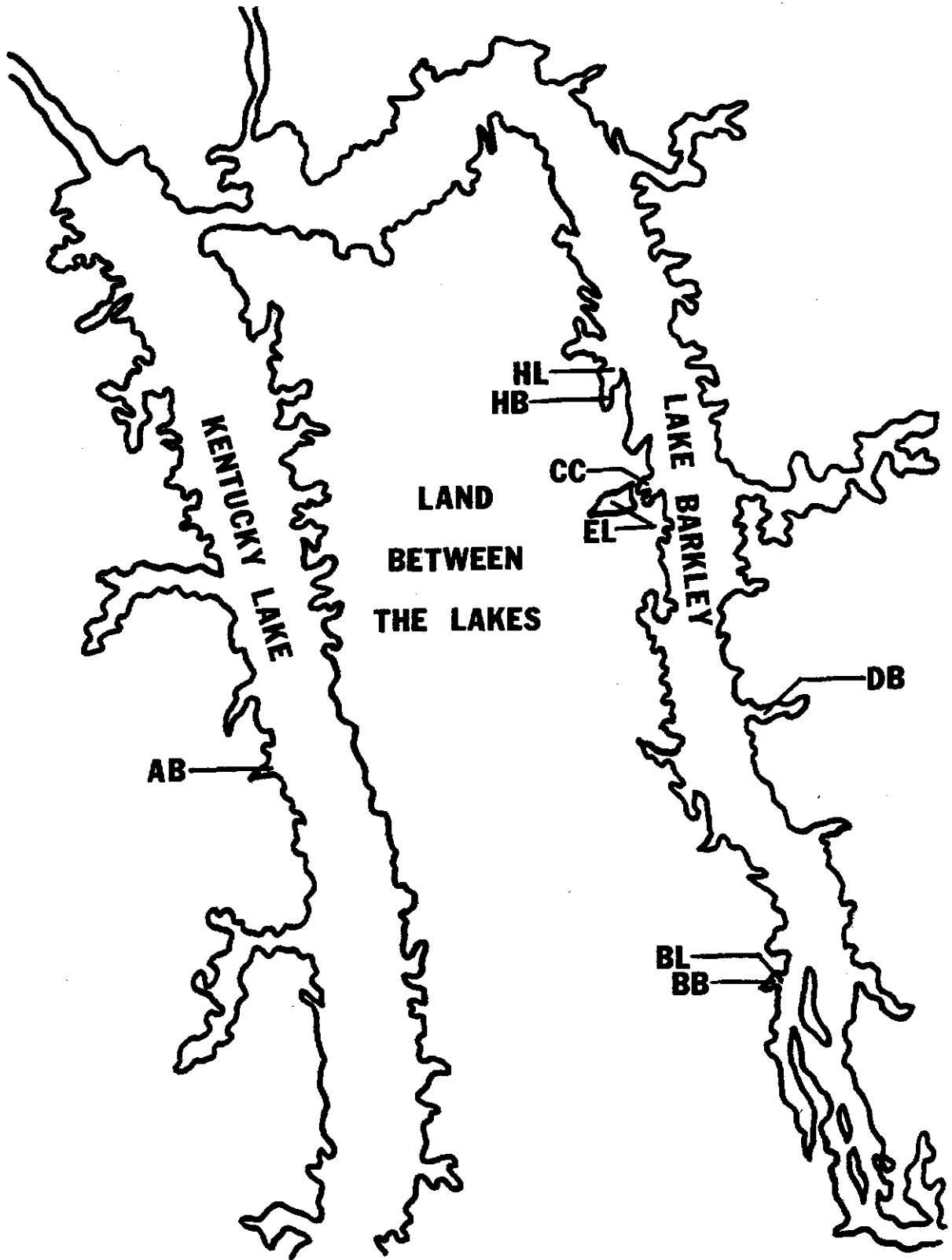
Ho. = concentration and length are mutually independent (no correlation)

* = reject Ho. at 0.05 level



MAP 1-A
SAMPLING SITES

**MAP 1-B
SAMPLING SITES**



LEGEND FOR MAP 1-A

CR-I	Cumberland River Site I
CR-II	Cumberland River Site II
CR-III	Cumberland River Site III
CR-IV	Cumberland River Site IV

LEGEND FOR MAP 1-B

AB	Anderson Bay
DB	Donaldson Bay
EL	Energy Lake
CC	Crooked Creek
HL	Honker Lake
HB	Honker Bay
BL	Bards Lake
BB	Bards Bay

FIGURE 1 Pb in FISH (PPB)

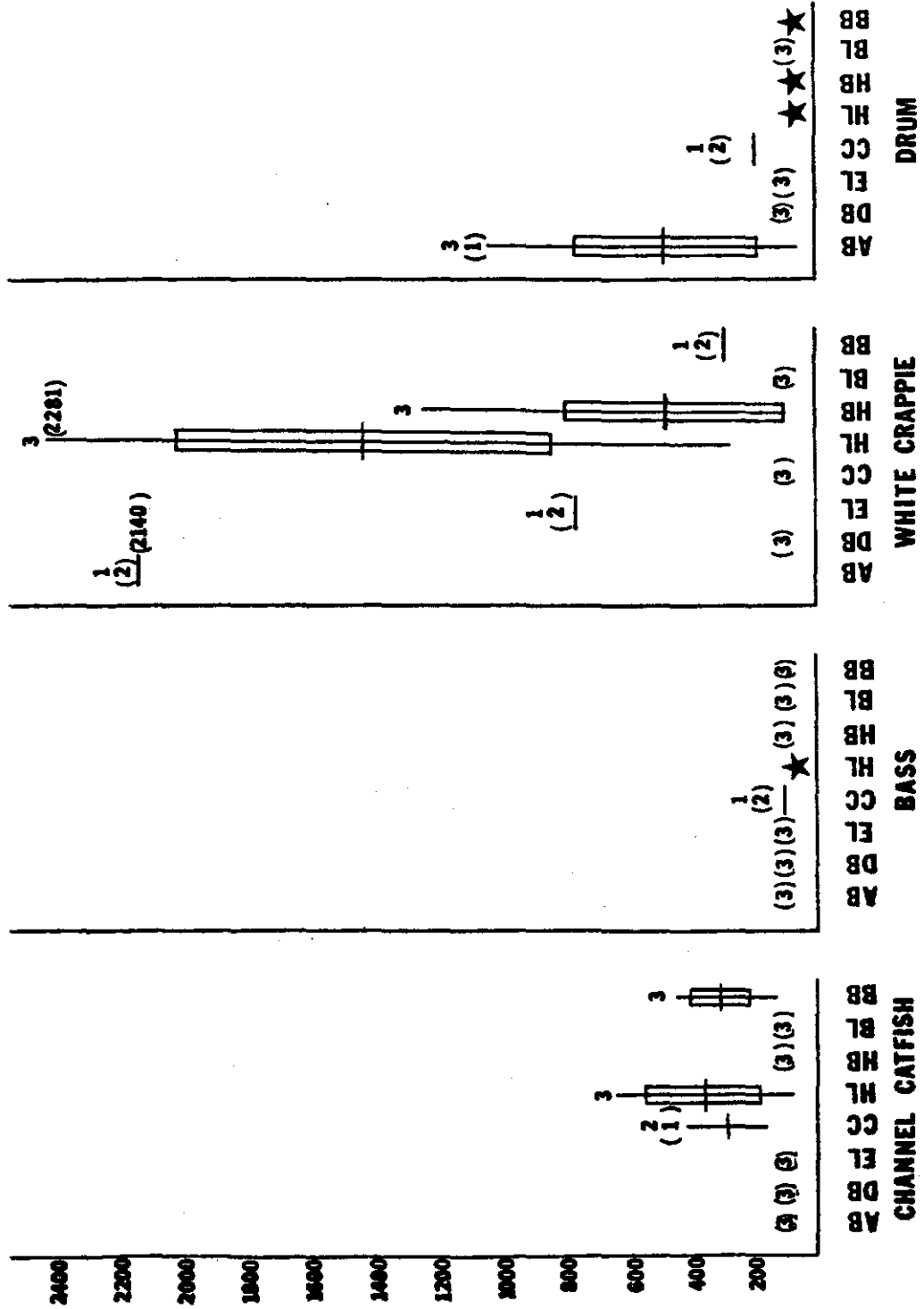


FIGURE 11 Cu in FISH (PPM)

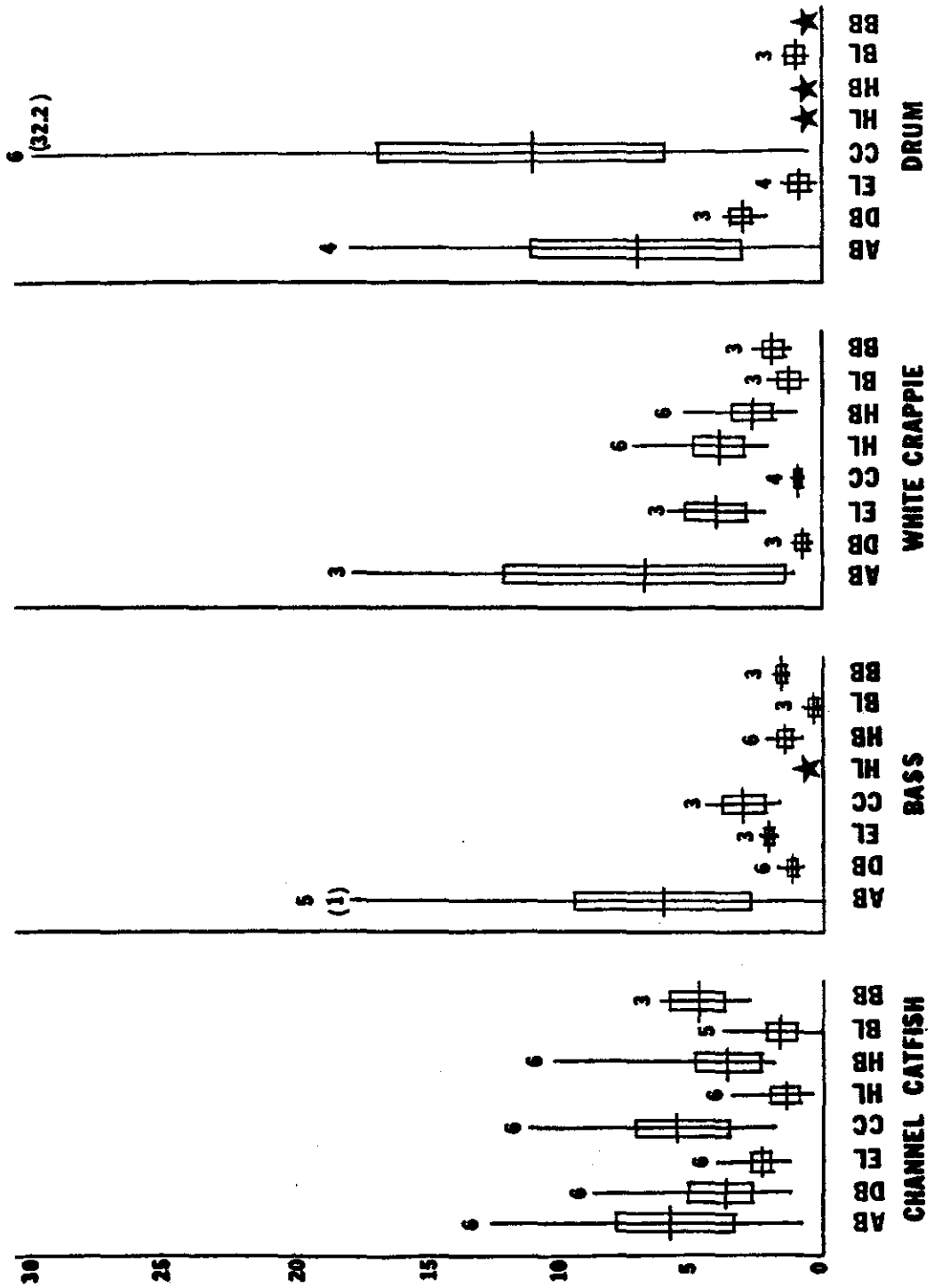


FIGURE III Cd in FISH (ppb)

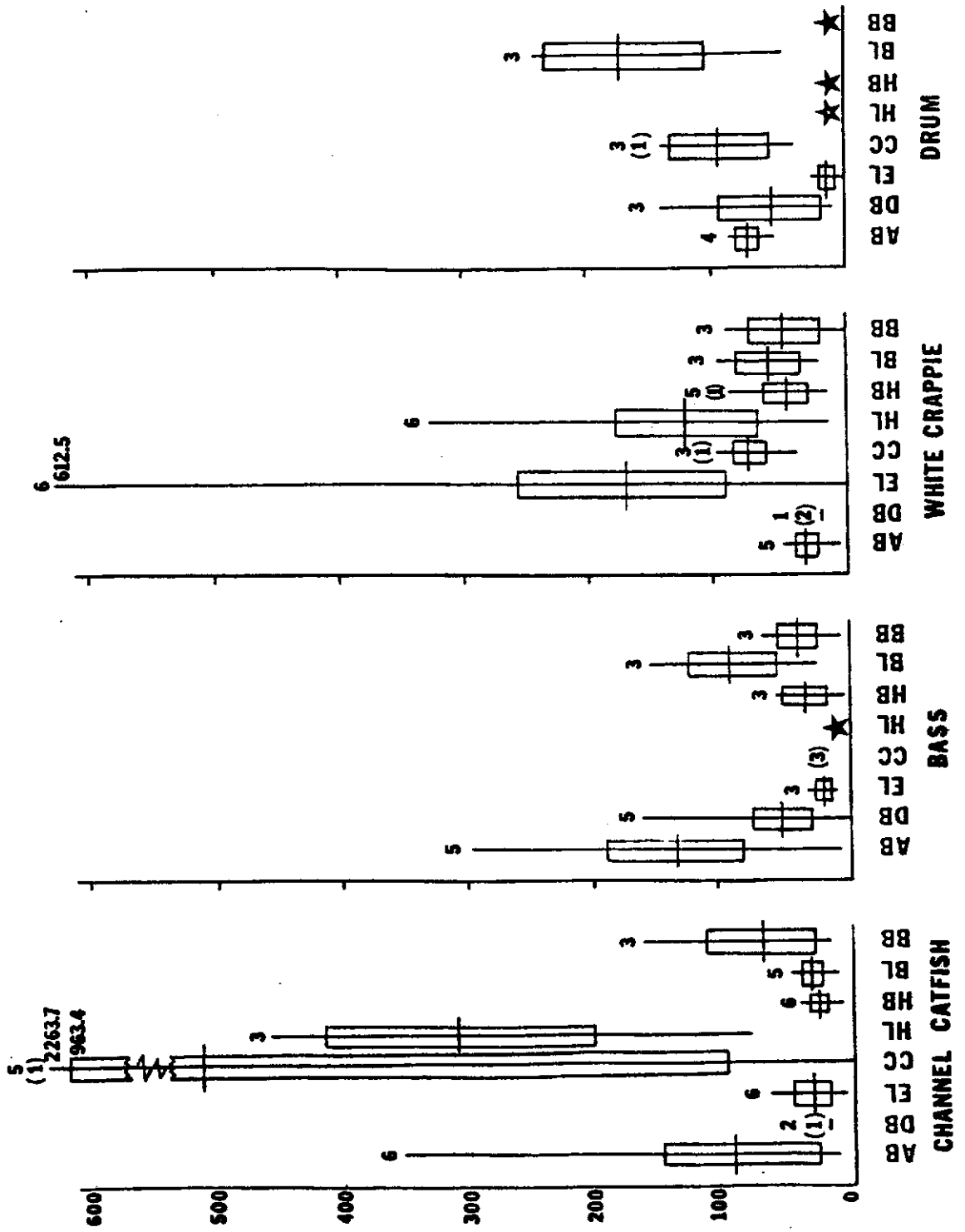


FIGURE IV Zn in FISH (PPM)

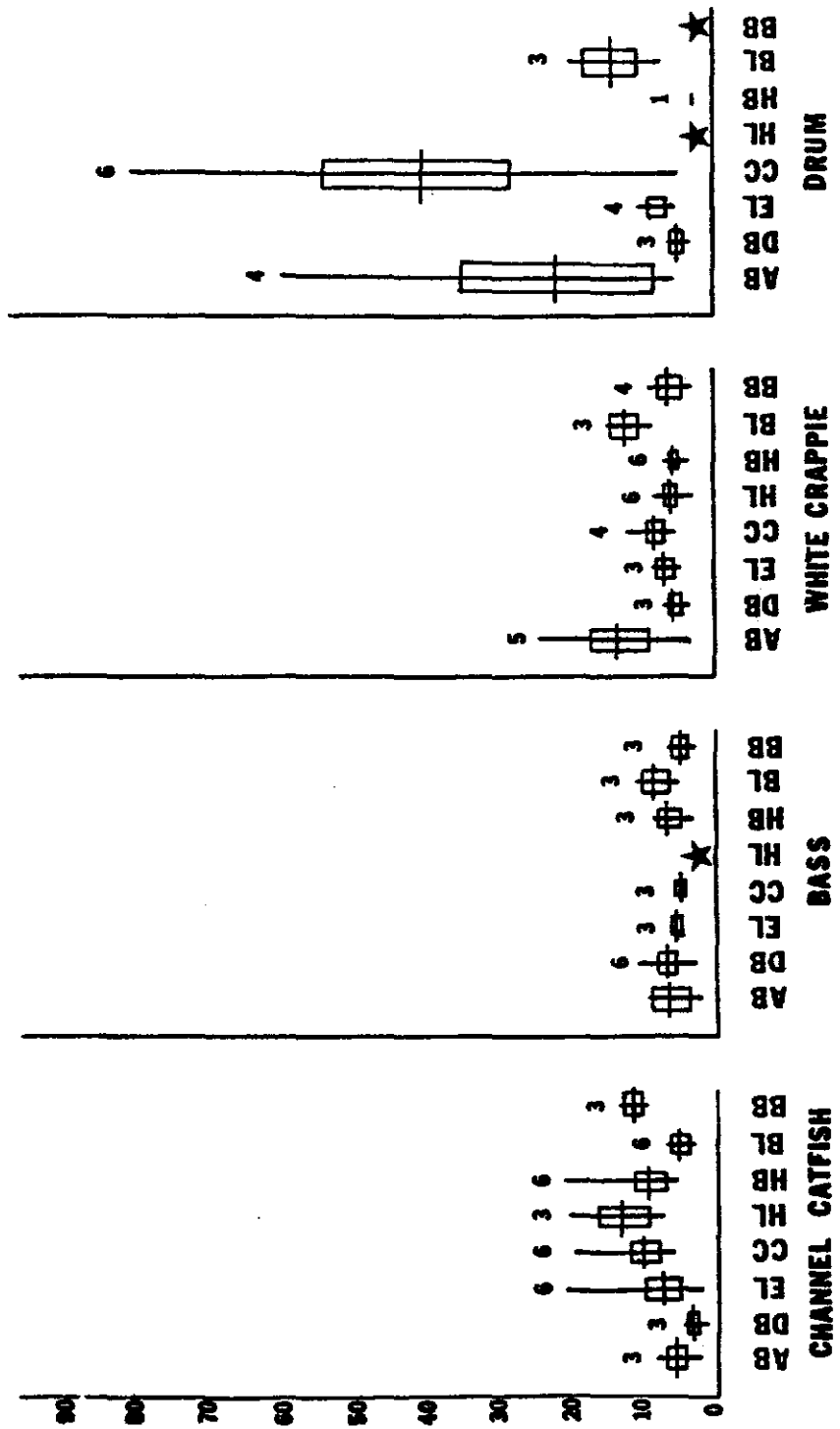


FIGURE V Cr in FISH (ppb)

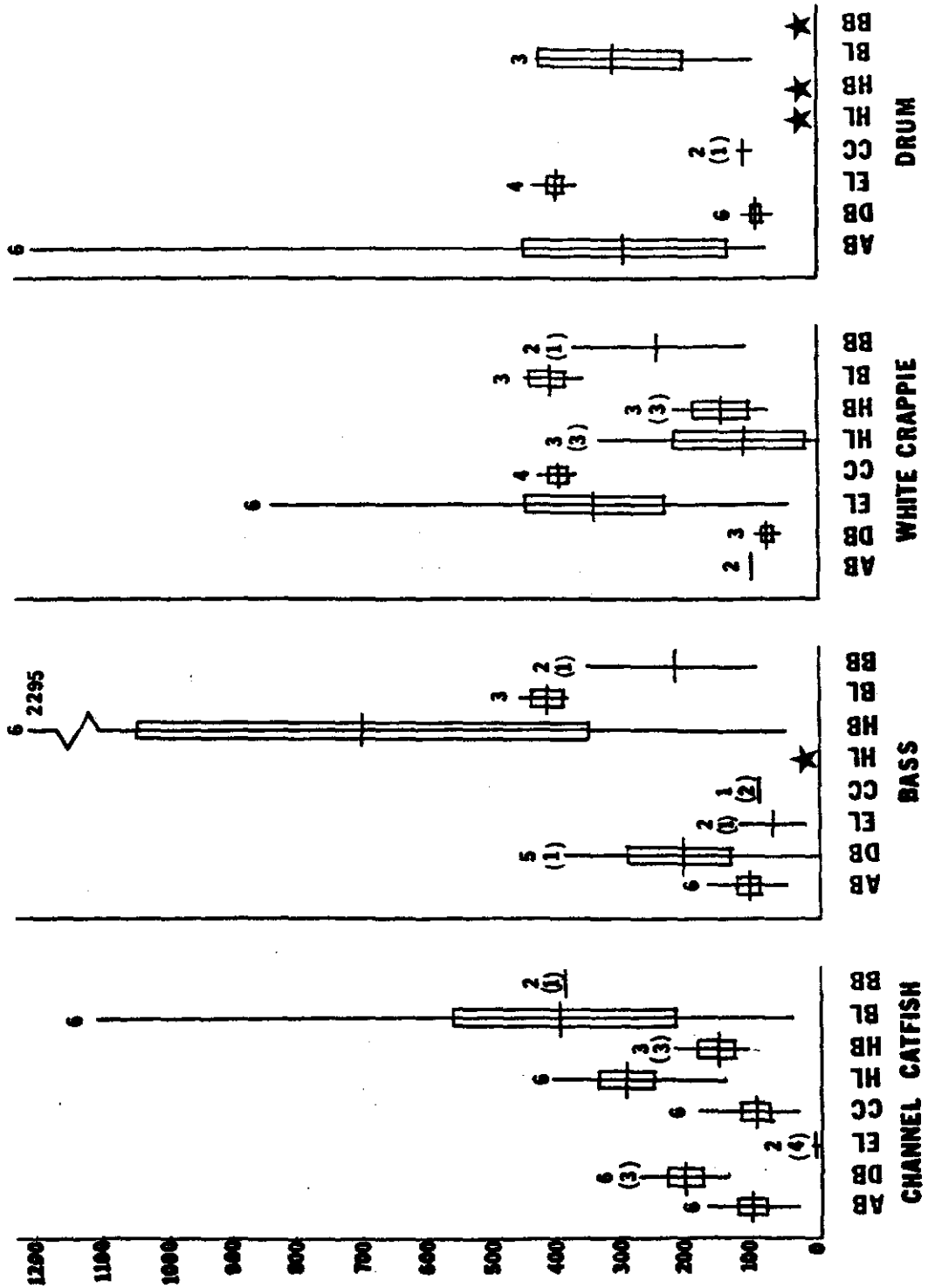


FIGURE VI Hg in FISH (PPM)

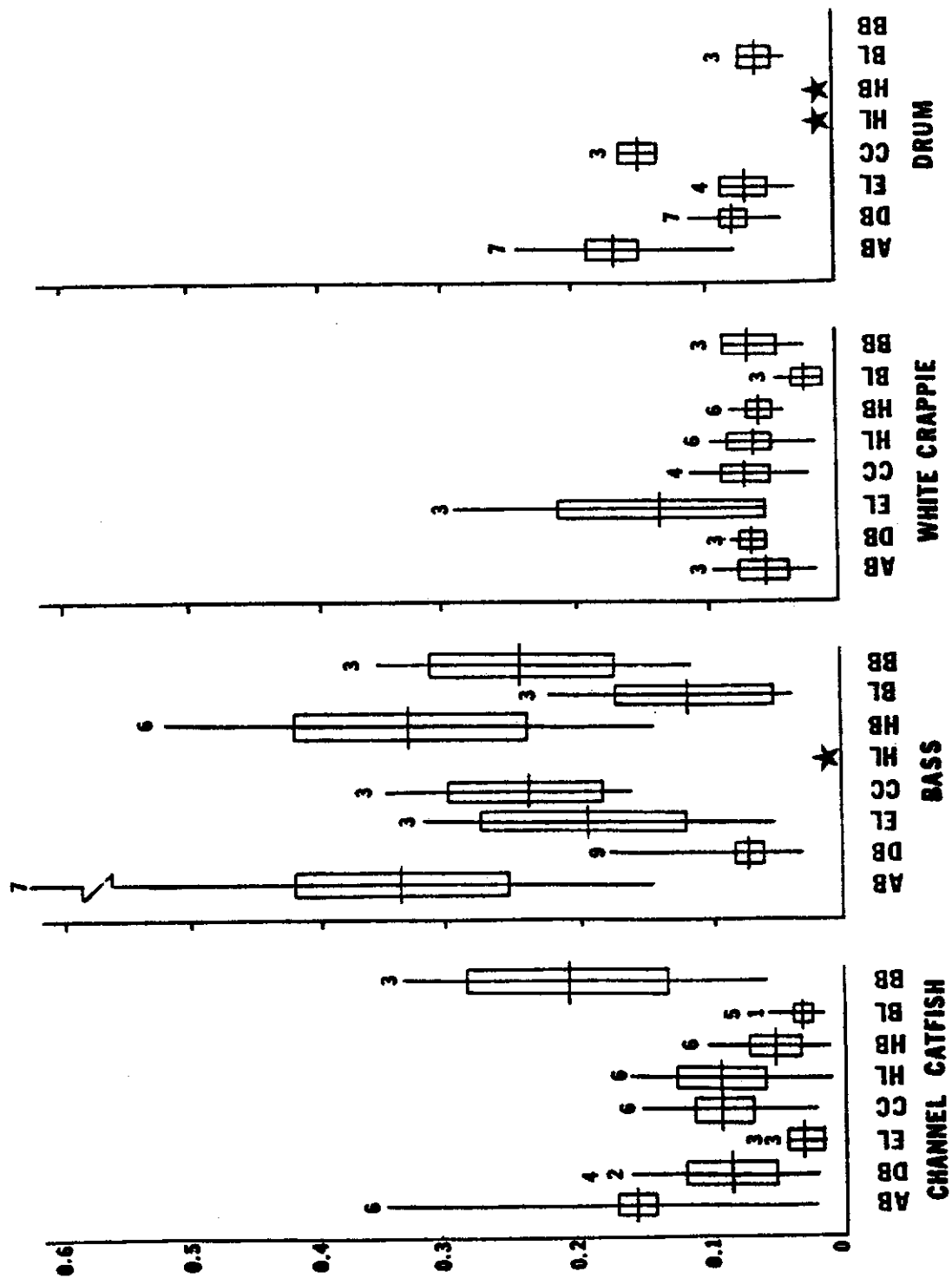


FIGURE VII Se in FISH (ppb)

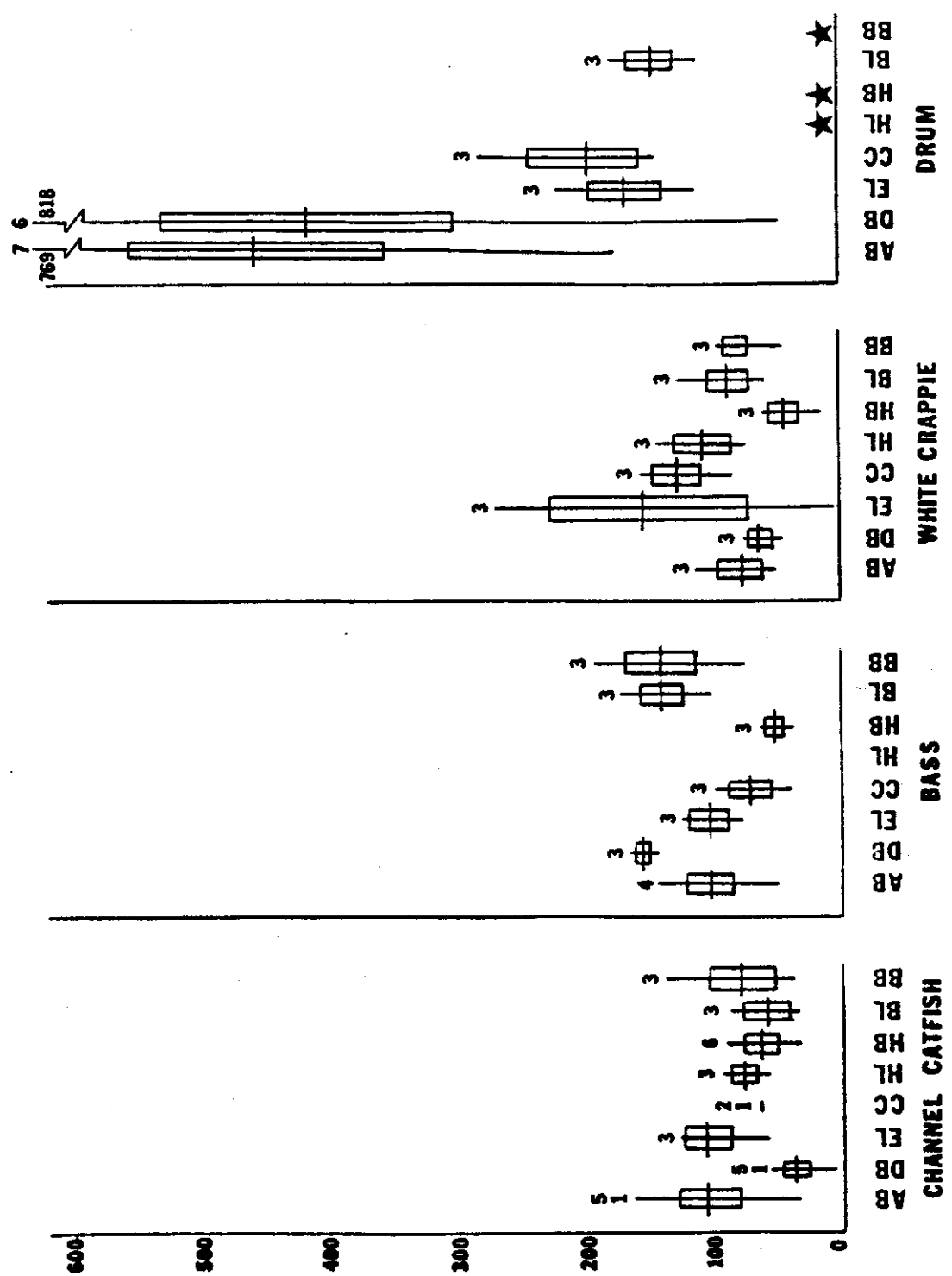


FIGURE VIII
COMPARISON OF METAL ION CONTENT BETWEEN SPECIES

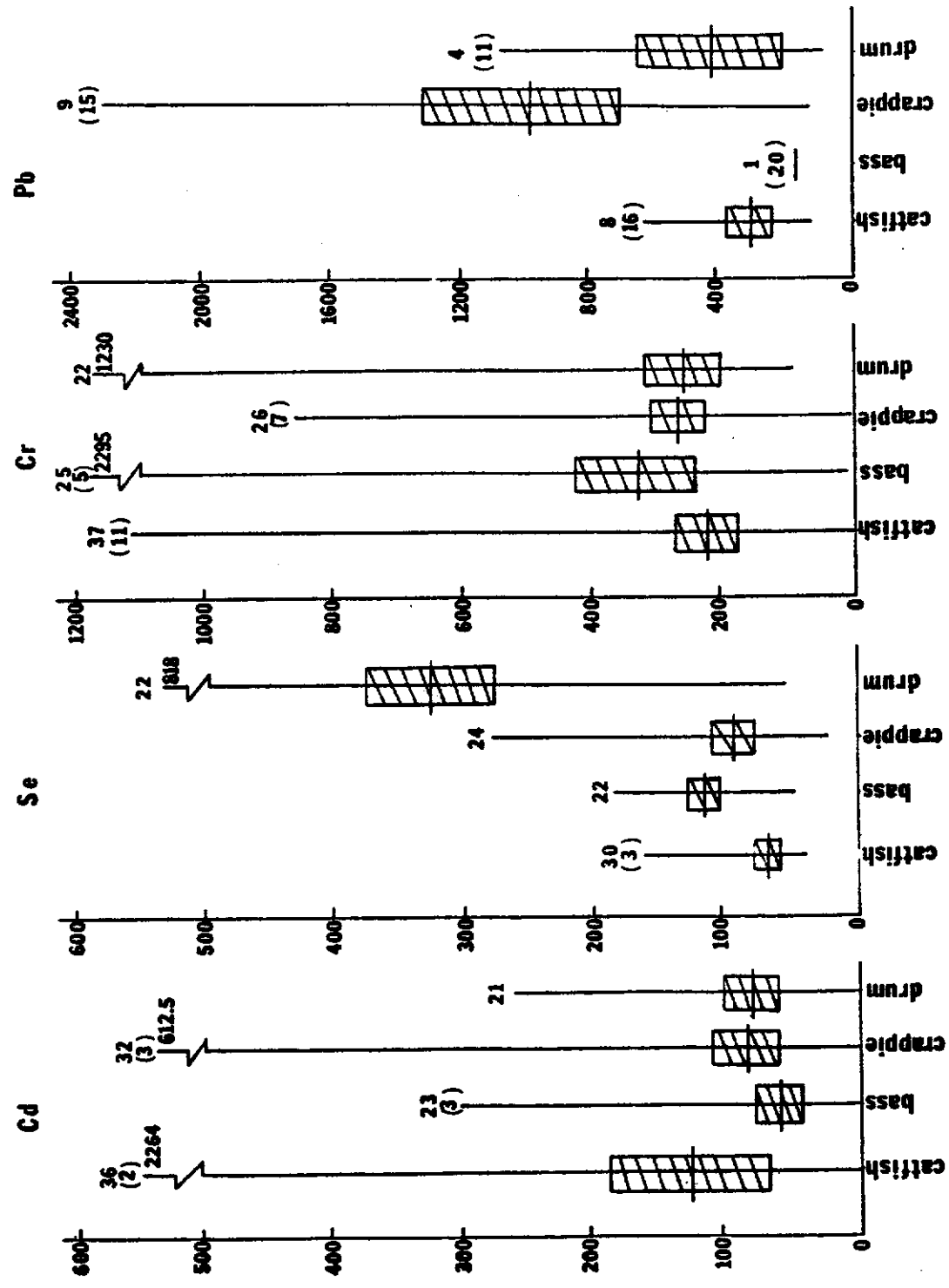


FIGURE IX
COMPARISON OF METAL ION CONTENT BETWEEN SPECIES

