State of California
The Resources Agency
Department of Fish and Game

AN ANALYSIS OF THE ANNUAL STRIPED BASS DIE-OFF IN THE SACRAMENTO-SAN JOAQUIN ESTUARY, 1971-72[1/] [2/]

by
DAVID W. KOHLHORST
Anadromous Fisheries Branch

SUMMARY

This study was conducted to provide a quantitative description of the die-off of striped bass (Morone saxatilis) and other species in the San Pablo-Suisun Bay area in 1971 and 1972 and to determine the most probable cause(s) of the annual mortality.

A total of 1,565 striped bass were found dead in 1971 and 1,763 in 1972. Since the 1972 survey was more extensive, both geographically and temporally, it was estimated that the mortality in 1971 was approximately twice as large as in 1972.

There was no evidence that the mortality was or was not selective for striped bass; a common or related cause of death was indicated for all species.

The 1971 die-off was centered farther downstream (Carquinez Strait) than the 1972 kill (Upper Suisun Bay) corresponding to greater saltwater incursion in 1972.

The periodicity of the striped bass die-off within a year seemed to be related to the tidal cycle. Climatological factors were significant only insofar as they affected searching efficiency.

Examination of freshly-dead striped bass in both years produced no evidence of incriminating heavy metal concentrations. Bacterialogical observations produced no known fish pathogens, although myxobacteria, a group containing pathogenic organisms, were isolated.

1/ Anadromous Fisheries Branch Administrative Report No. 73-7. Submitted May, 1973
2/ This work was performed as part of Dingell-Johnson Project California F-9-R, "A Study of Sturgeon and Striped Bass" supported by Federal Aid to Fish Restoration Funds.

INTRODUCTION

Unexplained mortalities of striped bass (Morone saxatilis) and other species of fish occur each year in the late spring and early summer in the Suisun-San Pablo Bay area of the Sacramento-San Joaquin Estuary. According to many people, including Department of Fish and Game employees, this has been happening regularly for 20-25 years, varying only in magnitude from year to year. In some years, as in 1970, the kill is large enough to prompt a public outcry, while in most years, it is less significant.

Numerous attempts to determine the source of the problem have proven unsuccessful. Silvey and Irwin (1959) found no evidence of metallic poisoning, but did hypothesize that changes in the ecosystem in early summer led to the evolution of amounts of hydrogen sulfide in the shallow areas that could be lethal to fish. Hubbell (1971, unpublished) reviewed the entire history of the die-offs, provided background summary for the entire San Francisco Bay-Delta, and suggested several hypotheses to explain the mortality that required further testing.

The present paper covers the 1971 and 1972 surveys of fish mortality in the area extending approximately from Pittsburg downstream through the entirety of San Pablo Bay. Its purpose is to provide a quantitative description of the kill as it occurred in those two years and to determine the most probable cause(s) of the annual die-offs.

ACKNOWLEDGEMENTS

The planning and implementation of this project over a two year period required the considerable effort of many personnel from Department of Fish and Game Regions 2 and 3, especially Sterling Davis and Michael Rugg. Several Fish and Game Wardens and Fish and Wildlife Seasonal Aids from those regions were indispensible in accomplishing the field work. Personnel of the Water Pollution Control Laboratory and the Fish Disease Laboratory, supervised by Richard Hansen and Harold Wolf, were responsible for the chemical and bacterial analyses. Jerry Turner and Harold Chadwick provided planning leadership to the project and critically reviewed this paper. I wish to sincerely thank everyone involved.

METHODS AND PROCEDURES

A field sampling program, both by boat and shoreline walking, was conducted in the areas where past die-offs had occurred.

In 1971 the lower limit of the survey area was defined approximately by a line connecting the rock wall off Mare Island and the town of Rodeo. The survey extended upstream to the State Highway 37 bridge on the Napa River and to the area of Chipps Island in Suisun Bay. Montezuma Slough was included in the early part of the 1971 survey, but few dead fish were seen there, so it was eliminated in the middle of that year. In 1972 the study area was extended to include all of San Pablo Bay.

The survey area was divided into sub-areas and these were numbered from downstream toward upstream (Figure 1). The divisions were rather arbitrary, although they attempted to define areas that were naturally discrete from one another. It was also necessary that the boundaries of the areas be related to readily identifiable landmarks to facilitate the location of the boat's position during the survey. Within each area (designated by a Roman numeral) the beaches were given alphabetical designations in ascending order, inasmuch as possible, progressing upstream. Only areas IV, VI, and X contained beach sampling locations. The three beaches in area IV were not surveyed in 1971 and two beaches, at Antioch and on the north shore of Sherman Island, were eliminated in 1972 and are not shown in Figure 1. Thus, nine beaches were sampled in 1971 and ten in 1972.

The sampling areas were surveyed by one boat two or three times each week from June 7 to July 12, 1971.

Two boats were used in 1972 and sampling assignments were divided into upstream and downstream sections. The downstream section consisted of those waters below the Carquinez Strait bridge and the upstream section, those areas above the bridge. Each section was sampled twice each week from June 5 to July 28.

The beaches were surveyed three times per week from June 11 to July 16, 1971, and from May 15 to July 28, 1972. The shore count was conducted by two individuals each survey day, with each person responsible for one-half of the beaches. The observers alternated beaches each week. Shore sampling coincided with low water, starting with the downstream beaches and moving upstream with the tide.

All accessible fish in both shore and boat surveys were identified, enumerated by location, measured, and cut completely in half to eliminate the duplication of observations.

In 1971, fish were measured inconsistently, some to the nearest 1/10 inch and some only to the nearest inch; often, lengths were estimated. For analysis, striped bass were arranged into five inch size groups. When possible, the sex of striped bass was determined. The occurrence of tagged striped bass was not recorded.

In 1972, all fish were measured in five-inch increments. No attempt was made to sex striped bass because most fish had been too decomposed in 1971. All tagged striped bass were recorded and the tags removed.

In 1971, all dying or very freshly dead (2-3 hours old) striped bass were chilled and transported as rapidly as possible to the Fish Disease and Pollution Laboratories at Nimbus. There they were examined for evidence of bacterial infection.

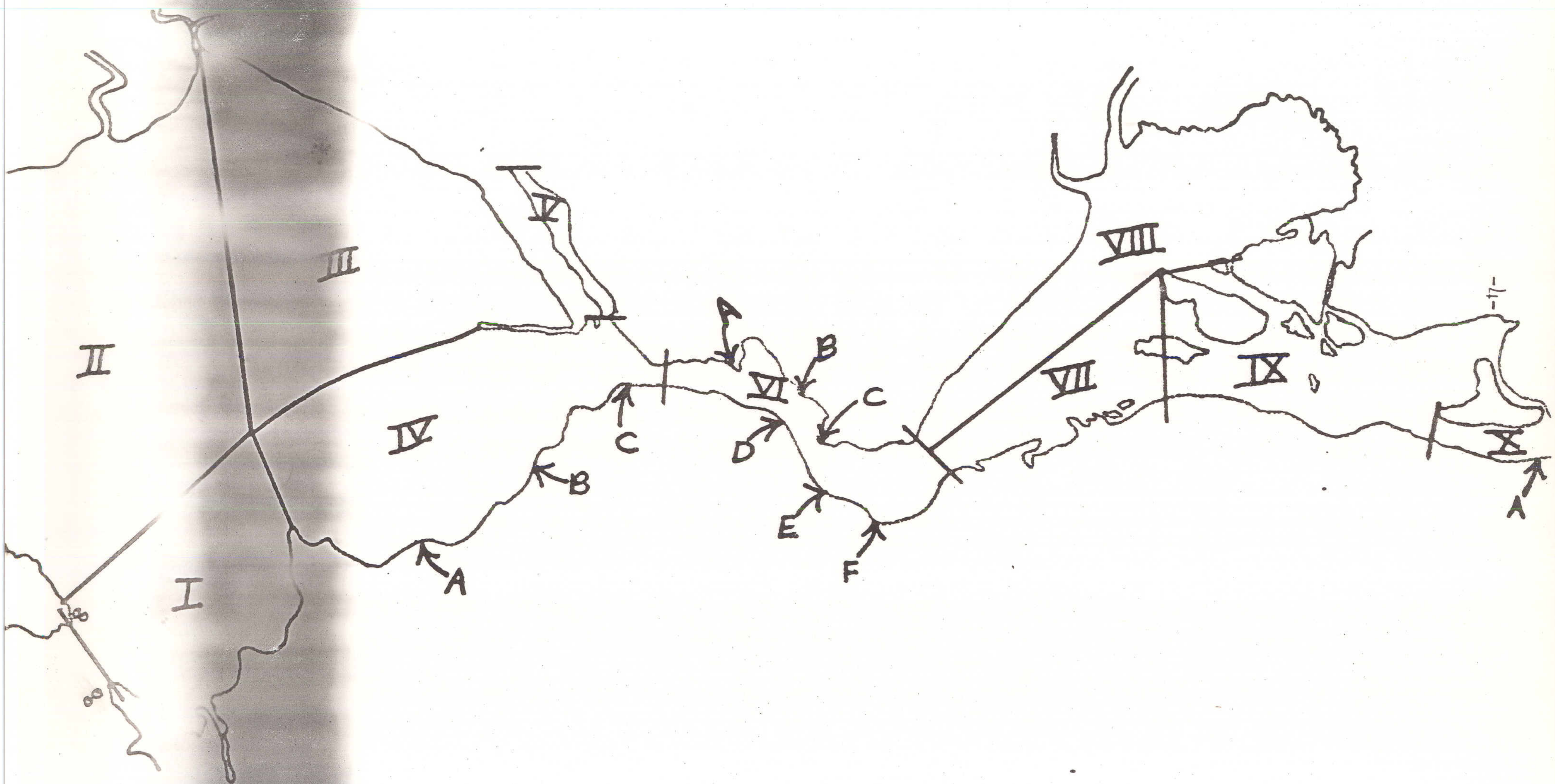


Figure 1. Striped bass mortality study sampling areas.

Bacterial and histological samples were collected in the field in 1972. Bacterial cultures from the liver, kidney and spleen were prepared on blood agar plates. Histological samples of the liver, kidney, spleen, and gill were preserved in Bouin's fixative. Observations were made of the condition of the fish, both internally and externally, noting particularly any abnormalities. The chilled or frozen fish carcass and the bacterialogical and histological samples were transported to the laboratory within 24 hours.

In both years laboratory determinations were made of the concentration of heavy metals in various body tissues.

RESULTS

Extent of Mortality

Based on those boat and shore areas surveyed in 1972, the observed striped bass kill in 1971 was 1,565 fish, with 921 seen on shore and 644 seen from the boat. Comparable figures for 1972 were 1,763, 1,029, and 734. The actual number of striped bass observed per unit of survey effort and, thus, the magnitude of the kill was considerably higher in 1971. In terms of the mean number of striped bass observed per area (or beach) per survey day, the 1971 beach counts were 2.5 times higher than 1972 and the 1971 boat counts 1.8 times greater. This would seem to indicate a 1971 die-off about twice as large as that in 1972.

Other Fish and Game Department boats operating in the area made observations of dead fish in 1972. A total of 241 striped bass were observed from these boats during June, 1972; none were reported in May or July. Most were not cut, so that repeated observations of the same fish were possible. These observations were not included in the analysis of the die-off.

Spatial Distribution of the Die-Offs

Arranging the survey areas and beaches in order from downstream toward upstream (Figure 2) demonstrated that the striped bass die-off was centered in a different location in the two years. The maximum mean number of striped bass per count for the 1971 shore survey was at beach VI-B (Benicia) and for 1972 was at beach X-A (Pittsburg). The corresponding maxima for the boat surveys were Carquinez Strait in 1971 and upper Suisun Bay in 1972. Thus, the kill occurred farther upstream in 1972.

Temporal Distribution of the Die-Off

The distribution of the striped bass kill during the survey period in 1971 and 1972 is graphically illustrated in Figures 3 and 4. A parabola was calculated to fit the survey data and was assumed to represent the changing abundance of striped bass in this particular area. Differences between the

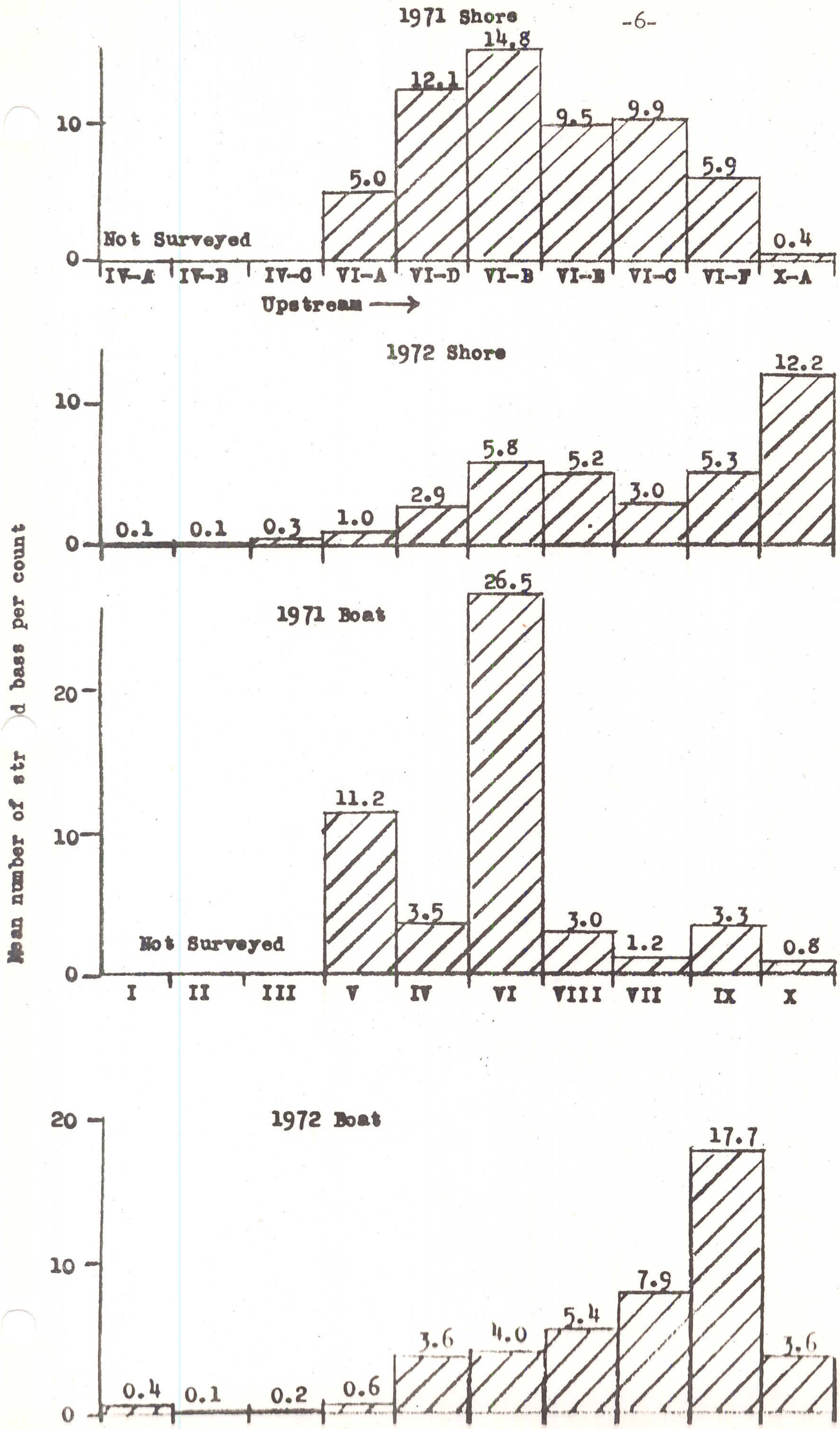


Figure 2. Distribution of the striped bass kill in 1971 and 1972 by survey areas and beaches.

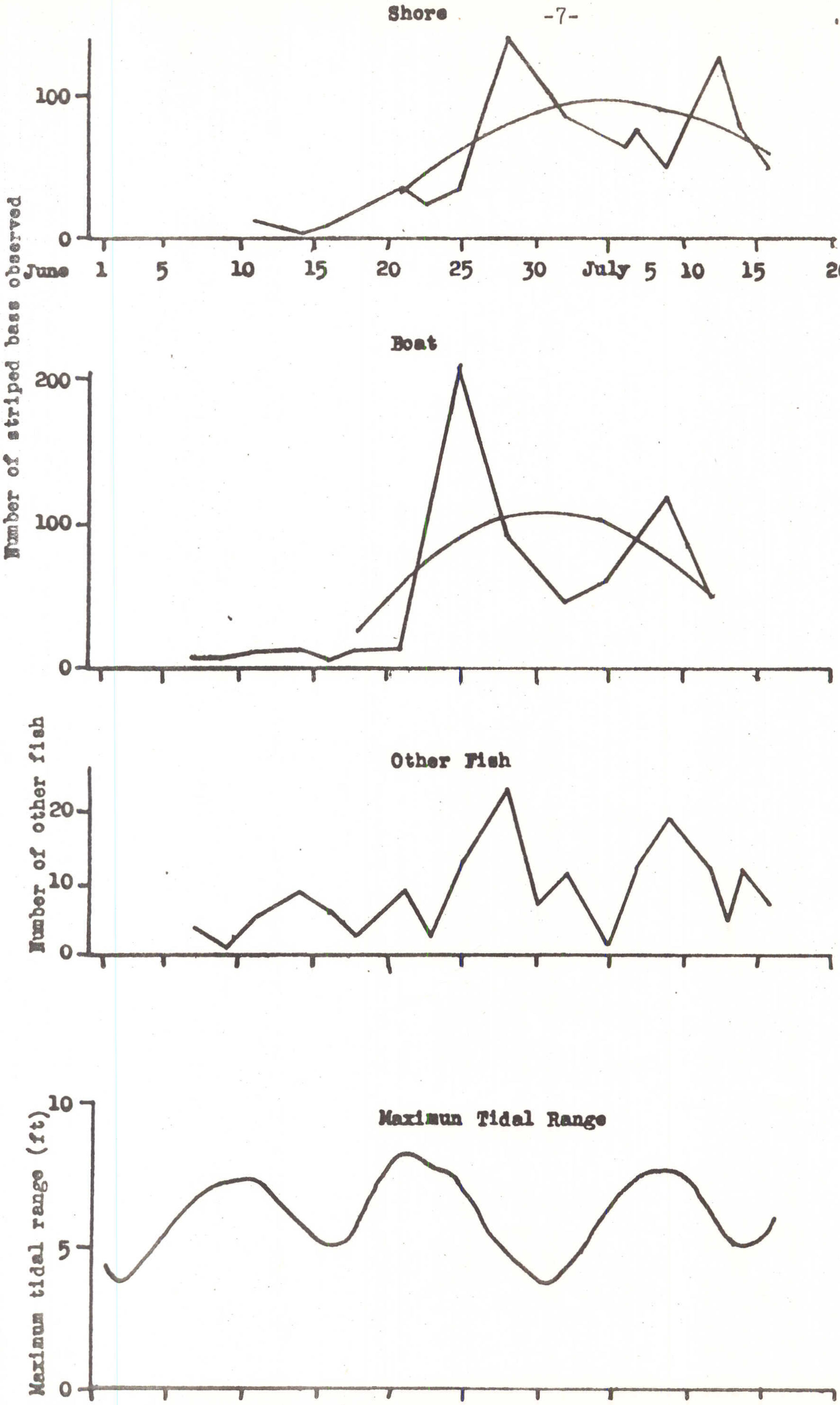


Figure 3. Comparison of 1971 shore and boat counts of striped bass, total counts of other fish, and the tidal cycle.

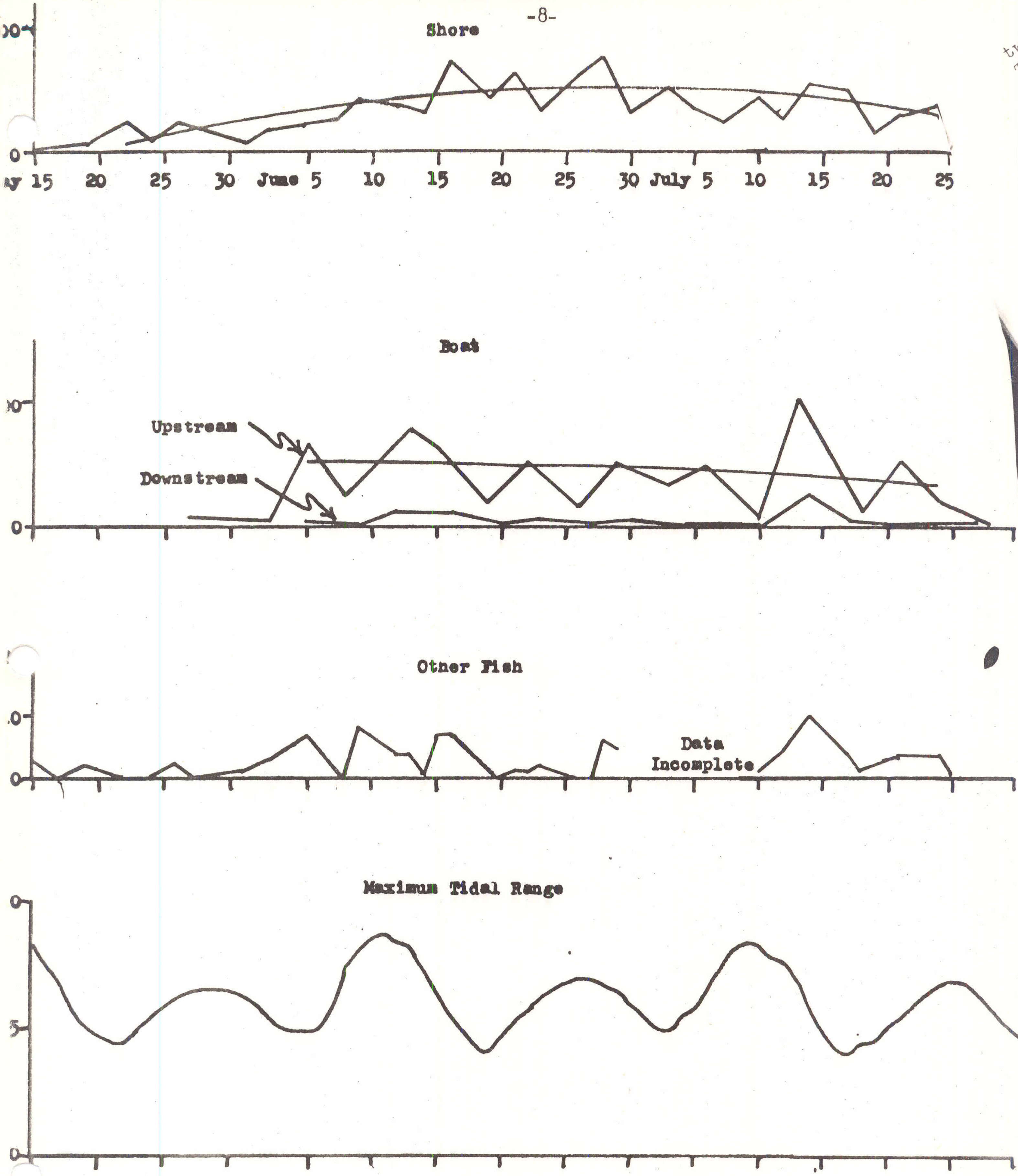


Figure 4. Comparison of 1972 shore and boat counts of striped bass, total counts of other fish, and the tidal cycle.

two years in the form of actual and calculated curves were very evident. The 1971 data showed pronounced peaks at approximately two week intervals, while such periodicity in the die-off was not as evident in the 1972 distribution. The shapes of the calculated curves also indicate a more pronounced peak of abundance in 1971. This might be an artifact of the shorter period of sampling in 1971.

Length Frequency and Mean Length of the Dead Striped Bass

The length frequency distribution and mean length of striped bass found dead in each year in both the boat and shore surveys was tabulated (Table 1). The discrepancy between the total number of fish in Table 1 and the total reported above resulted from the inability of the observers to measure some fish each year, especially in the 1971 boat survey. Also, some 1972 data were missing.

A comparison of the frequency distributions and mean lengths of the dead striped bass indicate a significant difference ($p < .005$) between the two years with respect to these two parameters. However, due to the sampling methods, it is doubtful that this is biologically significant. In 1971 many lengths were estimated rather than actually measured and the lengths in 1972 were grouped by five-inch increments.

Striped Bass of Known Sex

In 1971, those striped bass in suitable condition were identified as to sex. The length frequencies and mean lengths of these fish were determined and compared to the total die-off (Table 2). The combined mean length for males and females was significantly different from that for the total kill, as was the length frequency distribution ($\alpha = .05$). This indicated that fish suitable for sexing were the larger specimens encountered and were thus not representative of the true composition of the striped bass die-off.

A comparison of the male:female ratio in the die-off with that for the Department of Fish and Game 1971 creel census in that area showed that the ratios were quite similar, except for 30-35 inch fish (Table 2). In this length category, females were over-represented in the die-off with respect to the census.

Other Fish

The observed composition of the die-off of fish other than striped bass is shown in Table 3. The temporal distribution is depicted in Figures 3 and 4. The mean number found dead per day was generally greater in 1971 than in 1972. While a total of 20 species was observed, American shad (Alosa sapidissima) accounted for 68.6 percent and 48 percent of the total in 1971 and 1972, respectively. This shad die-off has been postulated to be natural post-spawning mortality, but a significant correlation (1971: $p < 0.01$, 1972; $p < 0.001$) between the number of shad observed on a given day and the number of striped bass casts doubt on this hypothesis and raises the possibility that the mortality affecting these two species is related. The same type of

TABLE 1. Size Distribution of the Striped Bass Kill.

Size	1971 Kill			1972 Kill				
	Boat	Shore	Total	Upstream Boat	Downstream Boat	Total Boat	Shore	Total
0-5"	(0%) 0	(0%) 0	(0%) 0	(0.3%) 2	(0%) 0	(0.3%) 2	(0.1%) 1	(0.2%) 3
5-10"	(4.1%) 7	(5.3%) 47	(5.1%) 54	(1.7%) 11	(1.3%) 1	(1.6%) 12	(3.1%) 30	(2.5%) 42
10-15"	(26.0%) 44	(40.6%) 363	(38.3%) 407	(29.8%) 195	(11.7%) 9	(27.9%) 204	(30.1%) 295	(29.2%) 499
15-20"	(33.7%) 56	(35.8%) 320	(35.3%) 376	(34.6%) 226	(27.3%) 21	(33.8%) 247	(31.1%) 304	(32.2%) 551
20-25"	(23.7%) 40	(12.0%) 107	(13.8%) 147	(20.5%) 134	(33.8%) 26	(21.9%) 160	(22.0%) 215	(21.9%) 375
25-30"	(7.7%) 13	(5.3%) 47	(5.6%) 60	(10.2%) 67	(19.5%) 15	(11.2%) 82	(10.9%) 107	(11.1%) 189
30-35"	(2.4%) 6	(0.7%) 6	(1.1%) 12	(2.3%) 15	(6.5%) 5	(2.7%) 20	(2.2%) 22	(2.5%) 42
35"+	(2.4%) 5	(0.3%) 3	(0.8%) 8	(0.6%) 4	(0%) 0	(0.5%) 4	(0.5%) 5	(0.5%) 9
Total	(100%) 171	(100%) 893	(100%) 1064	(100%) 654	(100.1%) 77	(99.9%) 731	(100%) 979	(100.1%) 1710
Mean Length	18.8	16.2	16.7	18.3	21.4	18.6	18.3	18.4

TABLE 2. Length Frequencies, by Sex, of the 1971 Striped Bass Die-off and the 1971 Creel Census.

	1971 Die-off					1971 Creel Census			
Length	Male	Female	Total	Ratio male: female	Total 1971 die-off	Male	Female	Total	Ratio male: female
0-5	0	0	0	-	0	-	-	-	-
5-10	1	0	1	-	54	-	-	-	-
10-15	10	3	13	3.3	407	-	-	-	-
15-20	14	14	28	1.0	376	249	241	490	1.0
20-25	7	10	17	0.7	147	186	280	466	0.7
25-30	4	5	9	0.8	60	63	74	137	0.9
30-35	1	5	6	0.2	12	17	12	29	1.4
35+	0	3	3	0	8	0	2	2	0
Total	37	40	77	0.9	1064	515	609	1124	0.8
Mean total	18.3	23.0	20.7		16.6	-	-	-	-
Mean legal	20.9	23.8	22.7		20.3			21.2	

TABLE 3. Summary of the Dead Fish (Other than Striped Bass) Observed in the Survey

Species	Total	Mean number per day	Total	Mean number per day
Shad	120	5.7	48	1.1
Sturgeon	6	0.3	8	0.2
Midshipman	8	0.4	15	0.4
Carp	9	0.4	9	0.2
Catfish	2	0.1	5	0.1
Salmon	3	0.1	0	0
Shark	2	0.1	0	0
Other*	25	1.2	15	0.4
Total	175	8.3	100	2.3

*Other includes:

White croaker
Perch
Sardine
Squawfish
Bullhead
Jacksmelt
Tomcod
Splittail
Starry flounder
Bluegill
Staghorn sculpin
Hitch
Northern anchovy
Unidentified species

relationship was also evident (although the correlation was not as highly significant: $p < 0.05$ in 1971 and 1972) when all other fish species observed were compared to the number of striped bass on a given day, reinforcing the hypothesis that some extrinsic factor was the causative agent for the mortality.

Striped bass were observed in the die-off much more often than all other species combined, the ratio being 6.0 striped bass: 1 other fish in 1971 and 17.6: 1 in 1972. It is unknown if the above ratios are indicative of the relative abundance of all species of the same general size as striped bass.

Bacteriological Results

A total of 20 freshly dead striped bass was examined for evidence of bacterial involvement in their death, eight in 1971 and twelve in 1972. In addition, 27 healthy control fish were collected from Clarksburg, Pittsburg, and Crockett in 1971. No control fish were examined in 1972.

The results of these determinations are shown in Table 4. While samples taken from the gut in 1971 did yield bacteria, such infections are not considered significant. Gut samples were not included in the 1972 program.

Six fish each year yielded isolates of bacteria from at least one organ, other than the intestine. Myxobacteria were isolated from one control fish and *Arthrobacter* from another; the organs of all other control fish were sterile. Since some myxobacteria are common fish pathogens, the difference in the incidence of infection between dead and control striped bass may be significant.

Gaffkya was the only known pathogenic organism identified. The significance of its occurrence is not known, but it may have resulted from contamination of the sample, since *Gaffkya* is normally a shellfish pathogen.

The lack of incriminating organisms and the low magnitude of infection indicated that the histological examination of the tissue samples collected for that purpose was not justified.

Heavy Metals

Heavy metal concentrations were determined in several tissues of seven striped bass found dead in the 1971 survey (Table 5). For comparison, seven healthy control fish were collected at Clarksburg, ten at Pittsburg, and nine at Crockett. Differences between dead and control fish were inconsistent, although there were higher concentrations of copper in the dead fish (except for the liver) than in the controls. The variability in individual measurements for different groups was great.

A similar analysis of 12 dead striped bass obtained in 1972 was in progress at the time this was written, but results were not available. No control fish were collected in 1972.

TABLE 4. Summary of the Results of the Bacteriological Examination of Dead and Dying Striped Bass Collected in 1971 and 1972 and Control Striped Bass Collected in 1971

Collection	Organ	1	2	3	4	5	6	7	8	9	10	11	12
Clarksburg, 1971 Control	Liver												
	Kidney												
	Spleen												
	Gut	M	M	M	M	L	L	L	A				
Pittsburg, 1971 Control	Liver		A										
	Kidney		A										
	Spleen		A										
	Gut		A		M			M					
Corckett, 1971 Control	Liver	M											
	Kidney												
	Spleen												
	Gut		M	M			A	Co	M	M Co			
Dead, 1971	Liver		C	M	M	M	M		M				
	Kidney				M	M		M	M				
	Spleen				M	M	M		M				
	Gut					M	M	M	M				
Dead, 1972	Liver		M					M					M
	Kidney		C					M		M		McAz	
	Spleen		Mc					G		M	M	M	

Key to abbreviations of bacterial types:

A = <u>Arthrobacter</u>
Az = <u>Azotobacter</u> type
C = Coliform
Co = Coccobacillus
G = <u>Gaffkya</u>
L = Lactobacillus
M = Myxobacteria
Mc = Myxococcus

TABLE 5. Mean Concentrations of Heavy Metals (in parts per million) in the Tissues of Striped Bass Collected in 1971

(Table prepared by H . Chadwick)

	Dead fish	Clarksburg control group	Pittsburg control group	Crockett control group
Mean length (in.)	18.1	22.2	18.7	19.4
		Copper		
Liver	9.7	17.5	9.9	13.6
Kidney	11.4	10.2	8.6	9.5
Gill	6.2	3.4	5.7 1/	5.0
Intestine	6.4	3.9	5.3	4.6
Flesh	2.3	1.4	1.2	1.2
		Zinc		
Liver	115.3	124.3	101.9	76.6
Kidney	192	112.3	140.1	76.6
Gill	107.5	113.1	170.0	126.8
Intestine	135.3	125	527.8	849.7
Flesh	31.5	31.1	33.8	32.6
		Cadmium		
Liver	1.4	2.1	1.7	1.4
Kidney	3.7	1.2	2.8	3.6
Gill	0.44	0.39	0.43	0.50
Intestine	0.77	0.11	0.61	0.45
Flesh	0.15	0.14	0.13	0.16
		Chromium		
Liver	0.24	0.55	0.23	0.11
Kidney	0.71	0.58	0.04	0.91
Gill	1.6	4.4	1.4	0.56
Intestine	0.33	0.18	0.12	0.29
Flesh	0.33	0.18	0.12	0.32
		Lead		
Liver	0.73	1.0	1.1	1.2
Kidney	1.9	1.1	3.1	2.7
Gill	1.8	1.6	1.4	4.2
Intestine	0.73	1.5	1.7	3.2
Flesh	1.3	0.90	0.99	1.4
		Mercury		
Flesh	0.33	0.72	0.30	0.30

1/ Excluding one fish with 600 ppm.

ANALYSIS

Effect of Tidal Factors

The inspection of Figures 3 and 4, and especially the 1971 data, reveals an approximate two-week cycle in the striped bass mortality curves. The most apparent environmental variable which corresponds to this periodicity is the tidal cycle, with high tidal ranges occurring at approximately 14-day intervals and maximum ranges (spring tides) at about 28-day intervals. These are periods of the lowest-low tide and highest-high tides, subjecting more of the extensive shallow water areas to exposure, followed by flooding. During these tides, animals at any location are also subjected to a greater range in salinity.

The tidal cycle during the period of the die-off was plotted in Figures 3 and 4 for comparison with the striped bass mortality curves. It appeared that higher tidal ranges were followed by larger bass die-offs and minimum ranges by low mortality. Therefore, an attempt was made to quantify this apparent relationship, even without a knowledge of the cause and effect mechanism.

Linear correlation coefficients for the relationship between two tidal variables, tidal range and electrical conductivity range, and several measures of striped bass mortality were calculated. The results of this were so inconsistent that they are not presented. Thus, the relationship between tidal factors and striped bass mortality, while qualitatively apparent, is too variable to quantify at the present time.

It should be noted that the Port Chicago mean range of electrical conductivity was similar in both years, 11,756 in 1971 and 13,386 in 1972. However, the mean electrical conductivity each year was very different, 4,504 in 1971 and 16,832 in 1972, corresponded to estimated TDS values of 2,883 ppm and 10,857 ppm, respectively. Thus, the aquatic environment at this location had a much more saline character in 1972. Tidal fluctuations in salinity were equivalent in both years.

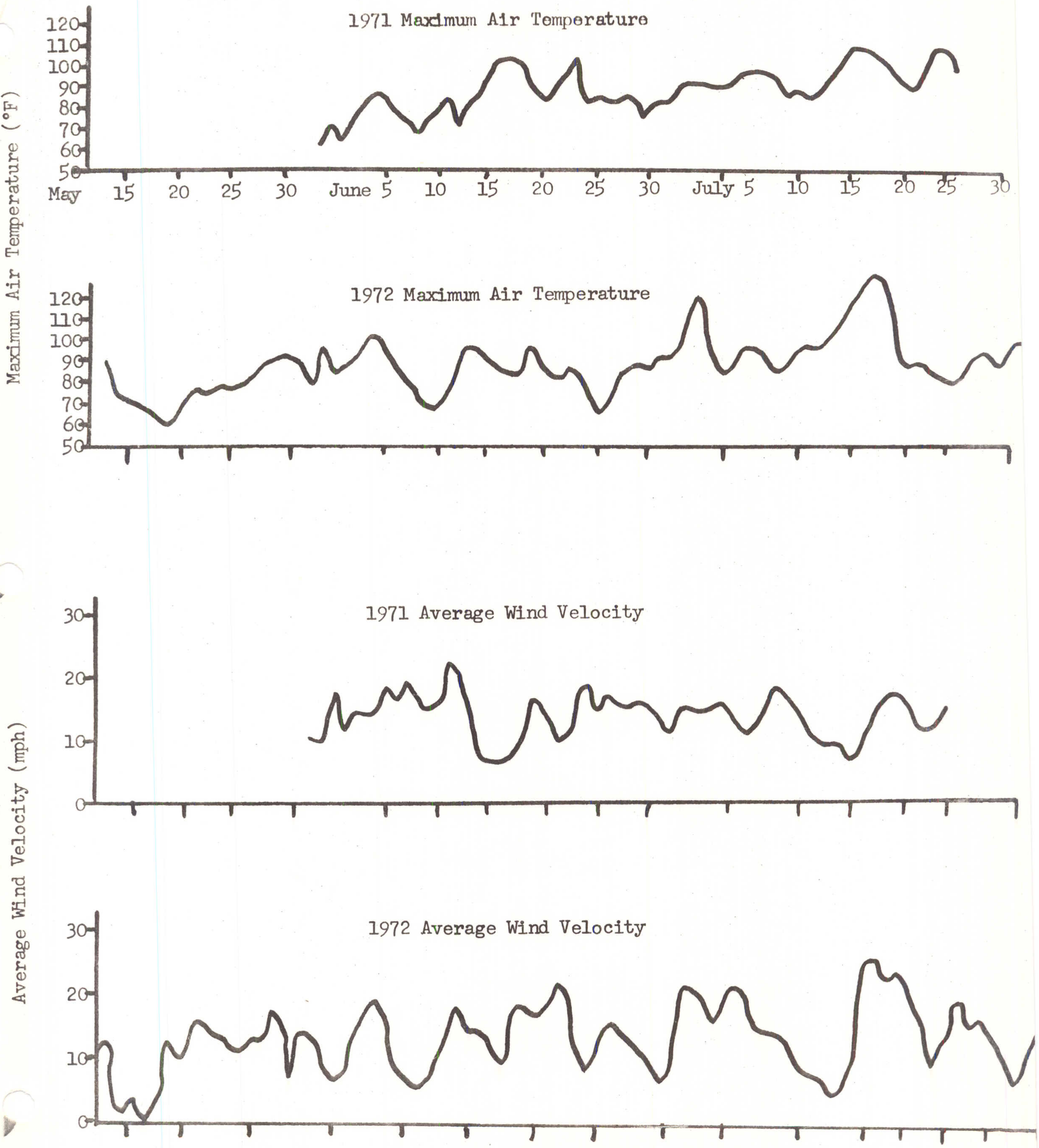
Effect of Climatological Factors

Previous reports of the apparent relationship between striped bass die-offs and the occurrence of warm, calm weather required an attempt at quantification. Climatological data for June and July, 1971, and May, June and July 1972, were obtained from the weather station at Travis Air Force Base.

Maximum air temperature and average wind velocity were chosen as the two pertinent variables. These two parameters were significantly correlated with one another ($p < .001$). Both showed a wider range of values during the period of study in 1972 than in 1971 (Figure 5).

There were no significant linear correlations between these climatological variables and either shore or boat observations in 1971. In 1972, there was a

Figure 5. Maximum Air Temperature and Average Wind Velocity at Travis Air Force Base for 1971 and 1972.



significant correlation between both factors and the upstream boat counts ($p < 0.05$). This may have been related to the difficulty in sighting floating fish under windy conditions with the prevailing westerly winds directed along the long axis of the estuary and producing considerable wave action. At these times the temperature was usually lower. Dead striped bass were seen more easily on hot, calm days.

Length Frequency and Mean Length

A comparison of length frequency distribution for dead striped bass with the total bass population in the area of the die-off could yield valuable information about any selectivity for size in the mortality. However, knowledge about the composition of the striped bass population was limited to the extent that a length frequency distribution could not be constructed for the whole population. The best available data were those from the Department of Fish and Game creel census in Carquinez Strait and Suisun Bay. These fish were all larger than 16 inches, the minumum legal size. The length frequency distribution and mean length of the angler catch and the legal size striped bass in the die-off for both 1971 and 1972 are compiled in Table 6.

While differences between distributions and means for creel census and mortality survey striped bass are statistically significant, they are not judged biologically significant because of their small absolute value. Since both the creel census data and the die-off data were samples of the same population, the difference between them must be taken as evidence that one or both were biased samples. Since one year's die-off mean length was larger and the other smaller, it seemed most probable that any bias was the result of inaccurate measurement of dead bass in various stages of decomposition. There is, therefore, no conclusive evidence that the mortality is selective for certain sized fish among those over 16 inches in length.

DISCUSSION AND CONCLUSIONS

The present study has not provided an explanation for the annual fish die-off in the Sacramento-San Joaquin Estuary. However, it has elucidated some relationships which may be pertinent to the solution of this persistent loss of fish.

A total of 1565 striped bass were found dead in 1971 and 1763 in 1972. These totals are an unknown fraction of the complete kill. In 1972, recoveries of Department of Fish and Game tags from dead bass were enumerated. Twelve of a total of 20 tag recoveries were found by our survey personnel and the remaining 8 tags were turned in by the public. This suggests that a maximum of 60% (12/20) of the die-off was observed by the survey. The actual percentage was undoubtedly much smaller. Numerous dead fish were observed on the islands in Suisun Bay during the boat surveys and offshore during beach surveys. These fish were inaccessible to the crews; therefore, they could not be cut in half and were not counted. Any fish decomposing beneath the surface also would not be seen.

TABLE 6. Length Frequency and Mean Length of Legal Size Striped Bass

Length	1971 kill		1972 kill		Angler catch in Suisun Bay and Carquinez Strait during June and July 1971		1972		Total	
15-20"	376	(62.4%)	551	(47.3%)	554	(43.6%)	621	(50.8%)	1175	(47.1%)
20-25"	147	(24.4%)	375	(32.2%)	532	(41.8%)	370	(30.3%)	902	(36.2%)
25-30"	60	(10.0%)	189	(16.2%)	160	(12.6%)	209	(17.1%)	369	(14.8%)
30-35"	12	(2.0%)	42	(3.6%)	25	(2.0%)	21	(1.7%)	46	(1.8%)
35 +	8	(1.2%)	9	(0.8%)	1	(0.1%) (0.1%)	2	(0.2%)	3	(0.1%)
Total	603	(100.0%)	1166	(100.1%)	1272	(100.1%)	1223	(100.1%)	2495	(100.0%)
Mean length (legal)	20.3		21.4		21.2		21.0		21.1	
Standard deviation	4.3		4.5		3.8		4.1		3.9	

There is no definitive evidence for believing that the mortality is, or is not, selective for striped bass. Although the striped bass is the most abundant species in the area in the size classes that are readily observed, it is not known if they are as numerous as indicated by the ratio of striped bass to other fish in the die-off.

The absence of many small fish (0-10") of all species, including striped bass, may be significant. Fish of this size are difficult to observe from the boats and may be subject to total and rapid consumption by the numerous gulls in the area. On several occasions, gulls have been observed to carry off fish of less than 10" in length. Most dead fish had previously been discovered and partly consumed by gulls. Whether this offers a satisfactory explanation for the absence of small fish in the kill is open to question.

The significant correlation between the number of dead striped bass and the number of other fish observed is evidence of a common cause of death for all species. Because of their importance and abundance in the die-off, striped bass have received the major effort in the analysis of the kill.

Some conclusions are evident from the present analysis. The location of the majority of the striped bass mortality varied between 1971 and 1972, with the die-off occurring further upstream in 1972. This mortality locus generally corresponds with the variation in the salinity gradient from year to year. A low runoff year, as 1972, results in more brackish water intrusion and fish losses further upstream. It was not possible to determine if the different net water velocities in the two years was responsible for the differing location of dead fish.

Related to this is the effect of daily tidal ranges (and ranges in total dissolved solid concentrations) on the magnitude of the die-off. Generally, high striped bass mortality follows a period of large tidal ranges and low mortality follows low tidal ranges. Efforts to quantify this relationship yield inconsistent results, indicating the non-rigid nature of the relationship between tides and mortality. The mechanism of action of this apparent cause and effect relationship is not understood. Factors other than osmotic stress are certainly involved, since fish inhabiting such an environment are expected to be well adapted to changes in salinity.

The mortality curves for striped bass in the two years are strikingly different in form, either as the result of the larger die-off in 1971; of differing environmental factors such as location, salinity and temperature; or of different migration patterns. Present knowledge is insufficient to determine which year shows the more "typical" mortality pattern.

Climatological factors (wind velocity and temperature) are important in determining the number of striped bass found dead by boat, but not on shore in 1972; or by either survey method in 1971. Since calm weather is ideal for sighting floating fish from a boat, this relationship is probably only a measure of searching efficiency. No evidence has been found to indicate that mortality itself is related to hot, calm weather.

A comparison of length frequencies and mean length of those striped bass dying in both years with one another and with creel census data yields little information since likely errors and biases probably exceed the differences observed. Since the creel census data are converted from a fork length measurement in centimeters to a total length measurement in inches, there is the possibility of round-off error. Also the dead fish are measured differently each year, with some lengths being estimated in 1971. Many dead fish are in poor condition for accurate measurement. All of these sources of error, combined with the large sample sizes, may result in significant differences unrelated to the causes of mortality. The inconsistency in the differences between the mean length of angler caught fish and the mean lengths of dead fish for the two years is further evidence of bias in measurement.

The results of heavy metal and bacterial analyses are inconclusive and, at the present time, there is no definitive evidence for their involvement in the mortality. The existence of bacteria of a group containing known pathogenic organisms in several tissues of dead fish is suggestive and should be explored. Only one occurrence of one known pathogen (*Gaffkya*) was documented, and this was a shellfish pathogen.

In the past, mention has been made of red tides in the area of the striped bass die-offs. While *Mesodinum rubra* blooms do occur in San Francisco and San Pablo Bays (Hubble, 1971, unpublished), there is no evidence of their involvement in the annual striped bass mortality. "Red water" or red tides were observed during the surveys in both 1971 and 1972 but no fish kills were directly associated with them.

While no evidence of hydrogen sulfide poisoning of fish was found, no major effort was made to study this particular hypothesis. Silvey and Irwin (1969) reported many bass dying in Southampton Bay in 1965 and 1966 and hypothesized that it might be due to hydrogen sulfide toxicity. At least in 1972, few dead striped bass were seen in Southampton Bay. In 1971, the generally large kill in Carquinez Strait produced numerous sightings in the vicinity of Southampton Bay. Whether these dead striped bass originated there is unknown.

LITERATURE CITED

Hubbell, P. 1971. Program to evaluate unexplained fish mortalities in the San Francisco Bay-Delta region. Report submitted to Deputy Director, California Department of Fish and Game. 21 p. (Typewritten).

Silvey, W. D. and G. S. Irwin. 1969. Relation of water quality to striped bass mortalities in the Carquinez Strait in California. Open-file report. U. S. Department of Interior, Geological Survey, Water Resources Division; 12 p.